A radionuclide tracer study of heavy metal cycling in Loch Etive, Scotland

A thesis submitted for the degree of Ph.D. by

Stuart Andrew Young
(B.Sc. Edinburgh)

The University of Edinburgh
Faculty of Science and Engineering
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Abstract

Seasonal variations in the behaviour of particle reactive heavy metals in Loch Etive, a fjordic estuary on the West coast of Scotland, have been investigated using the natural radioactive tracers ^{210}Pb and ^{210}Po. A multi-sample (water column samples; sediment traps; short sediment cores) time-series (monthly sampling for eighteen months) study is reported for one station in a stagnant, 140 m deep, basin. In all water samples a distinction between particulate and dissolved was made, by filtering through 0.45 μm filters. Emphasis has been placed on assessing the post-depositional mobility of Pb in organic-rich, high sedimentation-rate, coastal sediments. There was no renewal of the water in the deep basin during the study period, and the dissolved oxygen concentration gradually fell, to ~2.4 ml l^{-1}.

River and rainwater samples were analysed for ^{210}Pb and ^{210}Po in order to determine their input fluxes into Loch Etive. The mean particulate, dissolved and total ^{210}Pb riverine concentrations were 0.43 ± 0.33, 1.14 ± 0.93 and 1.30 ± 1.09 Bq m^{-3} respectively. The similar ^{210}Po concentrations were 1.77 ± 1.39, 2.60 ± 0.93 and 4.21 ± 3.01 Bq m^{-3} respectively. The total riverine ^{210}Pb and ^{210}Po flux, averaged over the whole surface of Loch Etive, was 149 ± 125 and 483 ± 345 Bq m^{-2} $year^{-1}$ respectively. The mean rainwater total ^{210}Pb and ^{210}Po activities of 53.8 ± 15.2 and 97.5 ± 107 Bq m^{-3} respectively, result in mean depositional fluxes to Loch Etive of 118 ± 33.5 and 214 ± 235 Bq m^{-2} $year^{-1}$ respectively. The relative importance of the riverine input reflects Loch Etive's large catchment area (~2000 km^3).

Water column particulate, dissolved and total ^{210}Pb and ^{210}Po concentrations were determined monthly for 17 months. The dissolved/particulate ratio was close to unity, which reflects the large concentration of particulate material in coastal samples. The surface (0-10 m) concentrations, varied greatly, depending on the amount of run-off in the weeks prior to sampling. The intermediate (10-60 m) and deep (60-120 m) water concentrations were more constant, with ^{210}Pb particulate, dissolved and total means: 0.17 ± 0.09, 0.18 ± 0.14 and 0.36 ± 0.20 Bq m^{-3} respectively. The corresponding ^{210}Po means were: 0.15 ± 0.07, 0.27 ± 0.19 and 0.42 ± 0.20 Bq m^{-3} respectively.

Several deep dissolved samples, taken in spring and summer had elevated ^{210}Po concentrations, suggesting preferential adsorption of ^{210}Po by spring bloom plankton, and subsequent remineralisation of decaying organic material at depth. Box model calculations indicated that the magnitude and frequency of remineralisation increased with depth. Water column ^{210}Pb and ^{210}Po residence times were determined monthly in the surface, intermediate and deep boxes. These relatively short residence

times (the mean values were 20.2 days for ^{210}Pb and 9.9 days for ^{210}Po) reflect the large particulate concentration.

Unpoisoned conical sediment traps moored at 5 or 20 m, 60 m and 135 m deep, were sampled monthly, and the major and minor element geochemistry and radiochemistry investigated. The total dry mass flux through the shallow, intermediate and deep traps was 127, 423 and 1285 g m^{-2} yr^{-1} respectively. The similar organic carbon fluxes were 22, 37 and 109 g m^{-2} yr^{-1}, while those for ^{210}Pb were 7.71, 131 and 421 Bq cm^{-2} yr^{-1}. Fluxes were greater at depth due to resuspension of material from the slopes of the deep basin, during tidal inflow of water. Greatest fluxes were found after inflows of dense water to intermediate depths.

Shallow (~60 cm or ~10 cm) sediment cores were taken in a transect of the loch, and the major and minor element geochemistry and radiochemistry investigated. The ^{210}Pb-derived accumulation rate was determined in the longer cores, and found to range from 0.178 to 0.216 g cm^{-2} $year^{-1}$. The accumulation rate in the shorter cores was estimated, but these are less accurate. The inventory of excess ^{210}Pb varied from ~0.5 to 1.8 Bq cm^{-2}, with the greatest inventories found in the muddy cores. The ^{210}Pb flux to the sediment surface at the same station as the sediment traps was estimated to range from 330-439 Bq cm^{-2} yr^{-1}.

The pore water ^{210}Pb concentration was determined in one core. The presence of a concentration gradient between bottom and pore waters indicated ^{210}Pb release. It is argued that this is insufficient to affect either the bottom water or sediment ^{210}Pb concentrations. There is only limited ^{210}Pb mobility in Loch Etive sediments, and it is suggested that any disagreement between dates by ^{210}Pb and other methods is due to variations in the sedimentation rate, or in the flux of ^{210}Pb to the sediment surface.

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Chapter One: Introduction

1.1. Fjords: Formation and Processes

Fjords, like other estuaries, are highly dynamic, semi-enclosed systems where freshwater and saltwater mix. This produces a harsh, turbulent environment with large environmental gradients, which make them interesting study areas. In addition they are usually easily accessible for study, and the resources required for study are modest compared to those required for open ocean study. (SKEI, 1983; EDWARDS & SHARPLES, 1991).

Fjords are restricted to mountainous areas in high latitudes, i.e. those previously glaciated: Alaska, Canada, Greenland, Iceland, Scotland, Scandinavia, the former Soviet Union, Chile and New Zealand. They were formed when the pressure of Pleistocene ice sheets overdeepened and widened pre-existing river valleys, but left rock bars or sills in places, particularly at fjord intersections, entrances and bends. Fjords generally have small width/depth ratios, steep sides, and an almost rectangular cross-section. They are generally very long (some reach 100 km in length), with large aspect (length/width) ratios. Right-angled bends are common. (DYER, 1979; SKEI, 1983).

Fjords are characterised by a series of basins, where slack currents allow sediment to accumulate, separated by sills where fast currents and rocky floors are common. The sills can be very shallow (< 5 m) and can restrict the free exchange of water with the sea. Often the water in deep basins is isolated and stagnates for months and years, until renewed by inflowing water of sufficient density. This renewal may be annual, or aperiodic and infrequent. In fjords with high organic production, or those with low inorganic sedimentary fluxes, infrequent renewal of bottom water can result in the

development of low or anoxic conditions. There is a spectrum of fjords from fully oxic (e.g. Fanafjorden, Ranafjord, Handangerfjord, Loch Fyne) through low oxic (Loch Etive), to oxic with seasonal anoxicity (Saanich Inlet), to anoxic with occasional flushing (Dramsfjord, Bolstafjord) to permanently anoxic (Framvarenfjord). There is thus a range of different fjordic environments that can be studied, often in close proximity to each other. (ANDERSON & DEVOL, 1973; HAMILTON-TAYLOR & PRICE; 1982; SKEI, 1988).

Suspended sediment carried by rivers, will settle out once current speeds drop on entering fjords. First sand then silt will settle out close to the river mouth, while clays will be carried further into the fjord. A high sediment input to the head of the fjord may create slumps that transport sediment into the basins as turbidity currents (SKEI, 1983). The clay particles settle slowly (~10 cm day^{-1}) unless they form larger aggregates which sink more rapidly (~5 m day^{-1}) (MCLUSKY, 1989). Aggregation is promoted by the presence of salt, which acts as a cohesive agent allowing clay particles to adhere together. In addition when salt water mixes with fresh, the density gradients formed promote collisions between clay particles, leading to enhanced aggregation (MCLUSKY, 1989), and this process is often termed salt flocculation (SHOLKOVITZ, 1976).

The clay particles may also be ingested by suspension-feeding plankton, which repackage the particles into faecal pellets, which settle rapidly, without much mineral alteration, even though the clays have passed through the digestive tract (LEWIS & SYVITSKI, 1983). Sinking rates of faecal pellets range according to their size and shape, SMAYDA (1969) finding rates ranging from 36-376 m day^{-1} in Narragansett Bay. Many authors have reported the importance of faecal pellets in ocean and coastal sedimentation (BEASLEY *et al.*, 1978; FISHER *et al.*, 1987) and in fjords faecal pellet sedimentation plays a major role. LEWIS & SYVITSKI, (1983) found faecal pellets to compose 0.3-87 % of total sedimentation in Howe Sound, Canada, depending on the grain size of the source material.

Sediment deposits in shallow parts of fjords may be subject to winnowing by tidal action or waves, where the fine fraction will be lifted off, and redeposited in the basin, leaving the coarser fraction behind. Typically the grain size of fjord sediments decreases with depth, while the sedimentation rate increases (SKEI, 1983). Occasional deep-water renewal events may erode slope or bottom sediments, causing resuspension and settling in the basin. The net transport of inorganic shelf sediment

into fjords by inflowing seawater was considered negligible by SKEI (1983), however MACKENZIE *et al.*, (1987) found the highly particle associated Sellafield waste radionuclide ^{241}Am present in Clyde Sea Loch sediments, a process they attributed to sediment movement.

Particle reactive heavy metals are incorporated into the sediment by various pathways. Firstly they may become associated with sedimenting particles in the surface layers of the fjord: they can be adsorbed into the lattices of clay particles; they can be directly uptaken by plankton, and incorporated into fæcal pellets and dead plankton detritus; they can be scavenged by humic terrestrial organic matter. Secondly they could be scavenged from the deep waters by these particles settling through the water column. They may also be scavenged by Mn and Fe oxyhydroxides, and this is particularly likely in the region of redox boundaries where high concentrations of these can build up due to oxidative-reductive recycling of these metals. Fourthly they may directly precipitate as insoluble sulphides or carbonates, especially in anoxic waters. Finally they could diffuse across the sediment-water interface, into anoxic sediments, where reductive precipitation may take place.

Fjords are particularly useful for modelling purposes since they are semi-enclosed and inputs from the atmosphere and rivers can be measured. Calculations of what is transported in and out over the sill, fluxes to the sediment and residence times of various elements in the water may be established. Indeed SKEI (1983) describes them as mini-oceans, in that they are usually highly stratified, and since the rate of processes may be orders of magnitude faster than those observed in the open ocean, empirical verification of models may be realistically attempted through experimental field study. Current progress in fjord research involves determining rate equations for fjord processes (EVANS *et al.*, 1979; EGEBERG *et al.*, 1988), close sampling of the redox boundary (EVANS *et al.*, 1979), investigation of dissolved and particulate species in the water column and the sediment (HAMILTON-TAYLOR & PRICE, 1982; JACOBS *et al.*, 1985), time-series studies (SANCETTA & CALVERT, 1988), and novel *in situ* sampling techniques, especially for pore waters (ANDERSON *et al.*, 1989).

1.2. Sediment Geochemistry: Mn, Fe, Organic Degradation

The degradation of organic matter in the top centimetres of sediments, drives their diagenesis, and controls the pore water and sediment concentration of their trace constituents. On burial the microbially mediated decomposition of organic matter uses up dissolved oxygen, Once this is depleted, other oxidants are utilised in a well-established, universal order depending on the thermodynamic free energy released per unit of reactive organic matter (FROELICH *et al.*, 1979; STUMM & MORGAN, 1981; DAVISON, 1985).

Table 1.2.1. Oxidation reactions of sedimentary organic matter (after FROELICH *et al.*, 1979). *depending on the mineral form of the oxyhydroxide.

Equation	Gibbs Free energy, DG° (kJ mole of glucose^{-1})
Aerobic respiration $138\ O_2 + (CH_2O)_{106}(NH_3)_{16}(H_3PO_4) \rightarrow 106\ CO_2 + 16\ HNO_3 + H_3PO_4 + 122\ H_2O$	-3190
Denitrification $94.4\ HNO_3 + (CH_2O)_{106}(NH_3)_{16}(H_3PO_4) \rightarrow 106\ CO_2 + 55.2\ N_2 + H_3PO_4 + 177.2\ H_2O$	-3030
Manganese reduction $236\ MnO_2 + (CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + 472\ H^+ \rightarrow 106\ CO_2 + 8\ N_2 + H_3PO_4 + 366\ H_2O + 236\ Mn^{2+}$	-2920 to -3090 *
Iron reduction $212\ Fe_2O_3 + (CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + 848\ H^+ \rightarrow 106\ CO_2 + 16\ NH_3 + H_3PO_4 + 530\ H_2O + 424\ Fe^{2+}$	-1330 to -1410 *
Sulphate reduction $53\ SO_4^{2-} + (CH_2O)_{106}(NH_3)_{16}(H_3PO_4) \rightarrow 106\ CO_2 + 16\ NH_3 + H_3PO_4 + 106\ H_2O + 53\ S^{2-}$	-380
Anaerobic respiration $(CH_2O)_{106}(NH_3)_{16}(H_3PO_4) \rightarrow 53\ CO_2 + 53\ CH_4 + 16\ NH_3 + H_3PO_4$	-350

A depth zonation of electron acceptors and associated reactions is thus established, (see **Table 1.2.1**), in the sediment, although the boundaries of the zones overlap. The disappearance of dissolved oxygen, and the onset of SO_4^{2-} reduction is usually taken as the oxic/anoxic (redox) boundary. The actual depth to the anoxic zone is highly variable, 'ranging from vanishingly small in sediments underlying productive continental margins, to tens of metres in slowly-accumulating carbon-poor pelagic

deposits' (SHIMMIELD & PEDERSEN, 1990), and is determined by the sedimentation rate, the organic content of the source sediment, the oxygen content of the overlying water and the depth of bioturbation.

The cycling of Mn and Fe about the oxic/anoxic boundary has been similarly well-established (LYNN & BONATTI, 1965; FROELICH *et al.*, 1979; DAVISON, 1985). The transition metal character of Mn allows it to exist in several oxidation states although only soluble Mn^{2+} and insoluble Mn^{4+} are common in the aquatic environment. Upon burial into the reducing sediments Mn^{4+} is reduced to Mn^{2+} which dissolves and slowly diffuses upwards along a concentration gradient, to the oxidised sediments, where Mn^{2+} is oxidised to Mn^{4+} and hence reprecipitated. A band of Mn thus accumulates just above the redox boundary (see **Fig. 1.2.1**). The thinner the oxic zone the higher the solid phase Mn concentration, and when this is buried it releases high dissolved Mn concentrations.

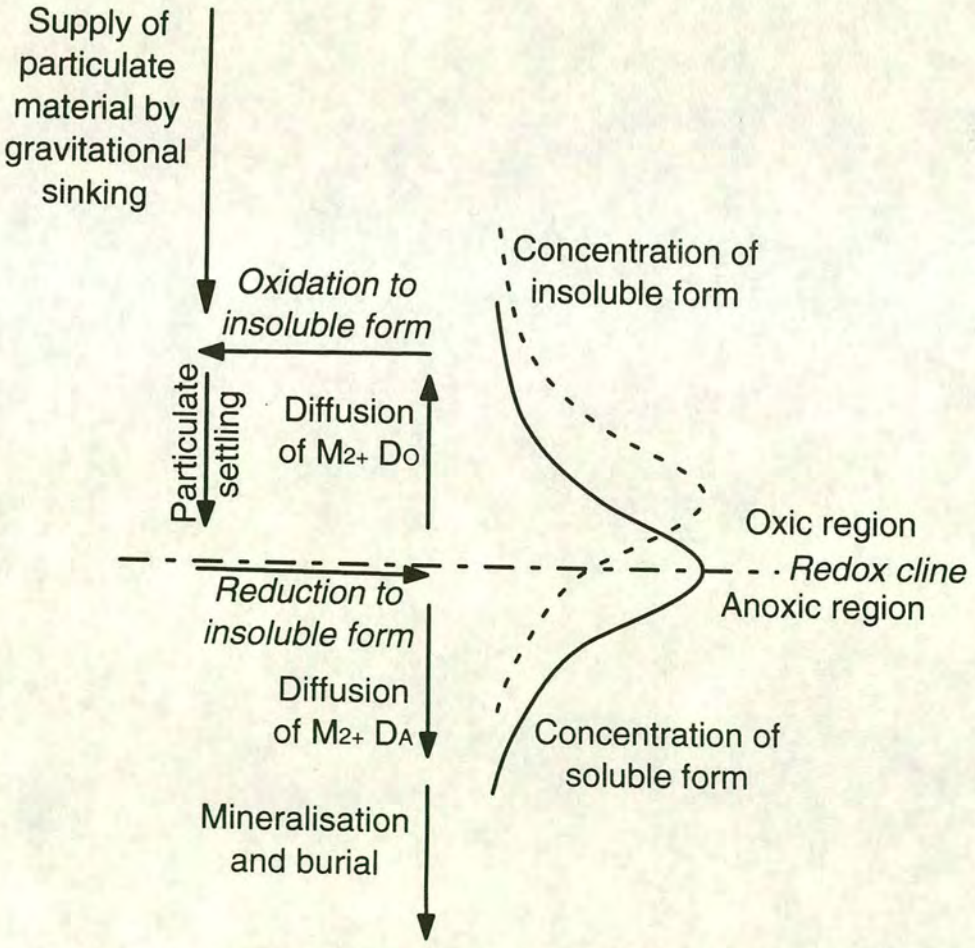


Figure 1.2.1. A model for Mn or Fe diagenetic cycling at a redox boundary (after DAVISON, 1985). D_O and D_A are diffusion constants.

Fe also has two common oxidation states, soluble ferrous Fe^{2+} and insoluble ferric Fe^{3+}. The dissolution and precipitation reactions occur during diagenesis in the same way as for Mn, but at a slightly lower Eh and hence slightly lower in the sediment column (STUMM & MORGAN, 1981). The well-observed colour-change from an oxidised red-brown surface to grey-green in the underlying sediments is attributed to Fe oxidation (SHIMMIELD & PEDERSEN, 1990). Mn is oxidised more slowly (STUMM & MORGAN, 1981) than Fe and it is possible for metastable high concentrations of Mn^{2+} to be found in oxic pore waters, and dissolved Mn can diffuse out of the sediments into the overlying water (SHIMMIELD & PEDERSEN, 1990). Mn oxyhydroxides forming in the water column, and sedimenting out, can scavenge dissolved trace metals and transport them to the sediment. The redox boundary can also move out of the sediment into the water column, and Mn dissolution-precipitation cycling also takes place, with establishment of an Mn concentration peak (HAMILTON-TAYLOR & PRICE, 1983).

1.3. Natural Decay Series Radionuclides: Aquatic Chemistry and Uses

The U/Th natural decay series consist of three radioactive decay chains from long-lived primordial parent nuclides (^{238}U, ^{235}U and ^{232}Th), through a succession of shorter-lived daughter nuclides to stable end nuclides (^{206}Pb, ^{207}Pb and ^{208}Pb). The ^{238}U decay series is shown in **Fig. 1.3.1.** with the nuclides of interest to this study highlighted. In a closed system, the activity of the daughter nuclide will eventually come to equal that of the parent nuclide due to the balance between radiogenic production and decay; this is called nuclear equilibrium. In the aquatic environment however, since each parent-daughter pair consists of different elements, with different chemistries, separation of the nuclides can occur, with the degree of disequilibrium depending on the rate of processes separating the two elements, and on the half-life of the daughter. The U/Th decay series nuclides are very useful in tracking particle and sedimentation processes, in the coastal marine environment.

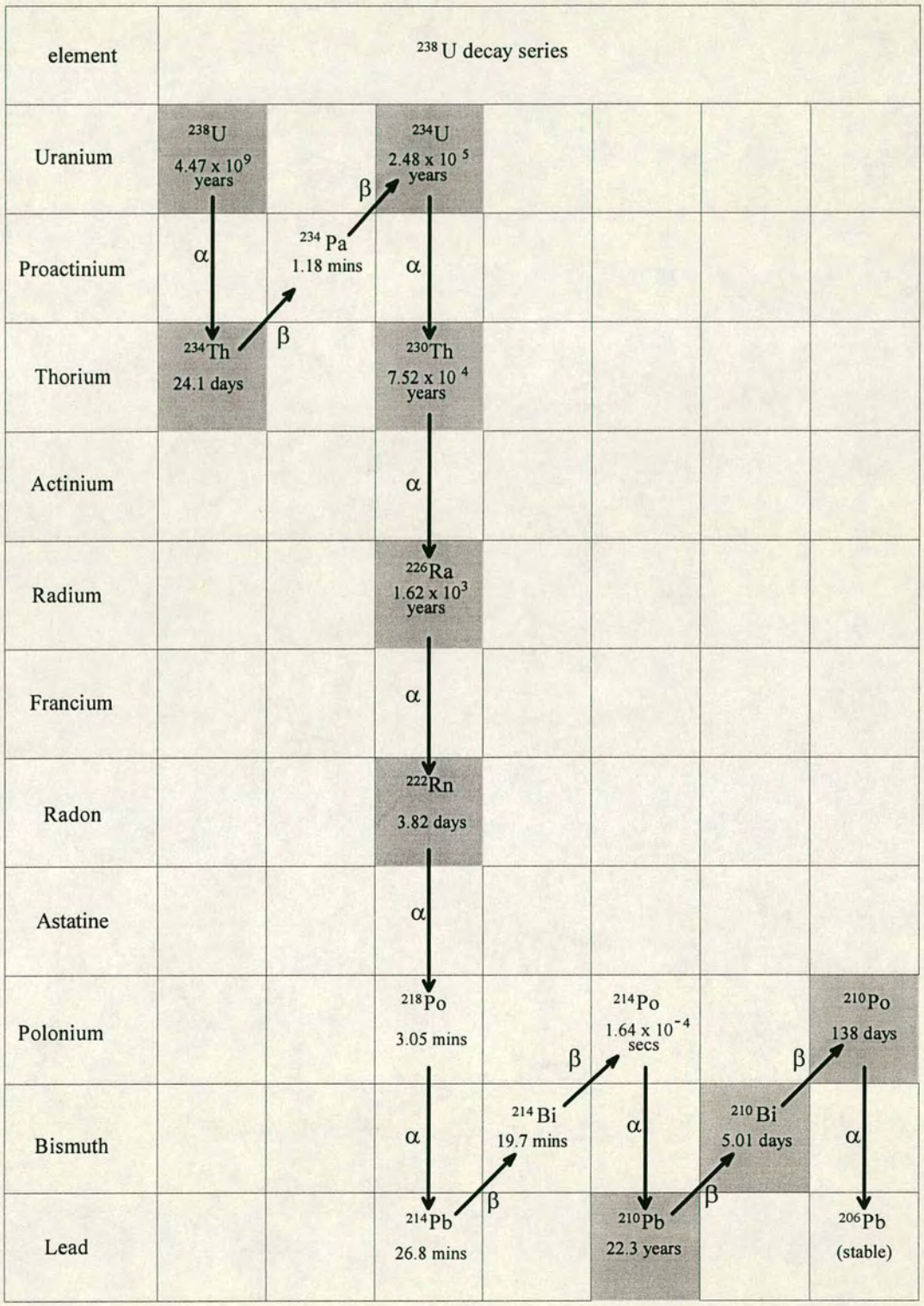


Figure 1.3.1. The ^{238}U decay series. (After BROECKER & PENG, 1982). Nuclides with half-lives greater than a day, are useful for environmental study and highlighted.

Table 1.3.1. Properties of the elements found in the ^{238}U natural decay series.

Element	Atomic Number	Group	Electronic configuration[1]	Electro-negativity[2]	Oxidation States[3]	Ionic Radii	Ionic Potential (z/R)	Solubility in Natural Waters
Uranium	92	IIIa	$6p^6 5f^3 6d^1 7s^2$	1.22	(3+) 4+ (5+) 6+	0.93,1.05	4.49 8.22	insoluble soluble
Thorium	90	IIIa	$6p^6 6d^2 7s^2$	1.11	(3+) 4+	0.99,1.10	4.25	insoluble
Radium	88	IIa	$6p^6 7s^2$	0.97	2+	1.52	1.35	soluble
Radon	86	0	$6p^6$	-	0	-		
Polonium	84	VIb	$6p^4$	1.76	4+ (2-)	1.02	4.25	insoluble
Bismuth	83	Vb	$6p^3$	1.67	3+ (5+) (3-)	1.09		
Lead	82	IVb	$6p^2$	1.55	2+ 4+	1.32 0.98	5.16	insoluble

Notes:

1 The inner electronic configuration is equivalent to that of Hg, $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10}$

2 There are several different scales of electronegativity, each gives broadly parallel results. These figures are those of Allred and Rochow.

3 Oxidation states in parenthesis are not commonly found in natural waters.

The solubility of the nuclides is governed by interactions with water molecules and other ligands, and such interactions are determined largely by the size and shape of the ion. Hence the oxidation state of the nuclide can influence its solubility. The ionic potential, Z/r (charge/radius), useful for describing the ions solubility, is shown in **Table 1.3.1.** for selected ions. At low values of Z/r simple hydration can occur, while at high values oxy-ion complexes can form; both of these result in highly soluble ions. At intermediate values of Z/r, hydrolysis can occur which results in insoluble ions.

The environmental chemistry of the ^{238}U decay products is illustrated in **Fig. 1.3.2.** ^{238}U is found in rocks, this or its soluble daughters may leach into groundwater and hence into the aquatic environment, or they may be transported via mechanical weathering. Since U forms the stable carbonyl complex, $[UO_2(CO_3)_3]^{4-}$, in water it is found uniformly distributed with salinity in the ocean. Consequently the production rate of its highly insoluble, short-lived daughter, ^{234}Th is known, and hence this can be used to track particle processes and sedimentation pathways on short timescales (MINIGAWA & TSUNOGAI, 1980; COALE & BRULAND; 1985, HUH & BEASLEY 1987; KERSHAW & YOUNG, 1988). Th is transported to the sediment surface via a two stage process, firstly it is adsorbed or scavenged by particles, and secondly these particles settle out. MCKEE *et al.* (1984), investigating the Yangtze river mouth area, found the residence time of ^{234}Th with respect to scavenging to range from 0.3 to 4.0 days, and with respect to settling from 0.5 to 11.0 days, with the time increasing with distance from the shore, and hence falling particle concentration. Similarly KAUFMAN *et al.* (1981) found the residence time of ^{234}Th with respect to removal from waters of the New York Bight to range from 10 days nearshore to 70 days at the shelf break. They also found that scavenging efficiency correlates better with salinity than with suspended particle concentration, even though it is the particles which perform the scavenging, since the salinity is a measure of the past particle concentrations of older water bodies. Removal of ^{234}Th is quicker in surface waters than deep waters. HUH *et al.* (1993) found the residence time of particulate Th to be 4 days in the upper 50m of the Santa Monica Basin, and 40 days in the entire water column. ^{234}Th has also been used to investigate the presence of the bottom nepheloid layer of the ocean (BACON & RUTGERS VAN DER LOEFF, 1989) and sediment re-working and mixing (COCHRAN & ALLER, 1979; ALLER *et al.*, 1980; ALLER & DEMASTER, 1984).

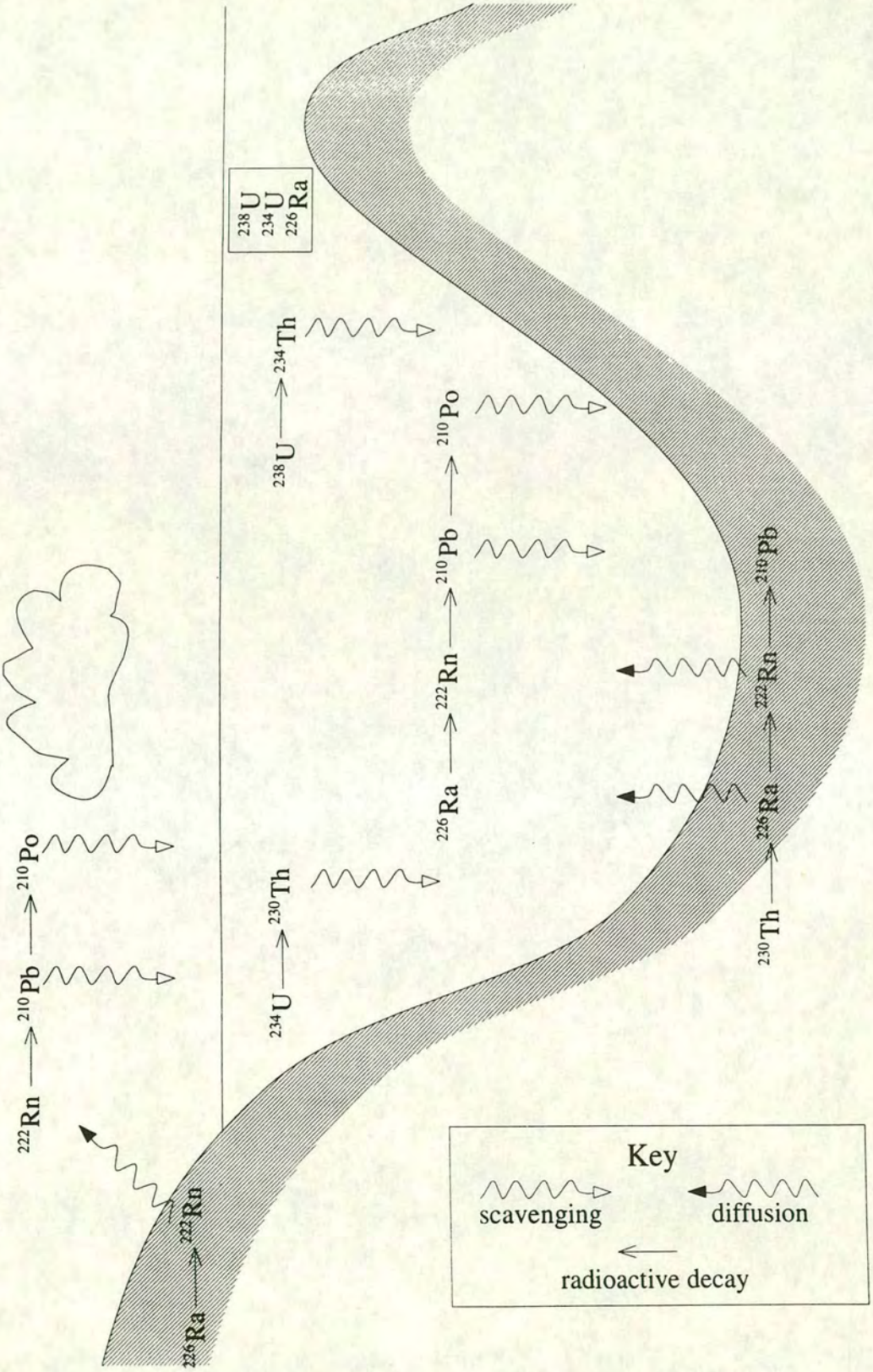


Figure 1.3.2. Aquatic environmental chemistry of selected ^{238}U-decay nuclides.

^{222}Rn gas emanates from the Earth's surface; once in the atmosphere it decays through a series of short-lived intermediates to the three longer-lived nuclides ^{210}Pb, ^{210}Bi and ^{210}Po. Since the products of nuclear decay are charged, they are chemically reactive, and become irreversibly associated with aerosols. The radionuclides are eventually either washed out by precipitation (wet deposition), or fall out under the influence of gravitational or electrostatic forces. (TUREKIAN *et al.*, 1977) The ^{210}Pb concentration in a precipitation sample depends on many meteorological factors, and varies enormously. Generally light rains have less diluted ^{210}Pb concentrations, as does the first fraction of a heavy rain (BASKARAN *et al.*, 1993). ^{210}Pb depositional flux is positively correlated with amount of precipitation, although with huge variation. No seasonal variation is apparent in temperate countries. The variety in measured ^{210}Pb precipitation causes problems in the estimation of annual fluxes; even an average of many monthly fluxes may be very uncertain.

The historical ^{210}Pb flux may be estimated from 'natural collectors' such as lichens, peat and soil profiles, lake sediments, salt marsh profiles and ice sheets. The ^{210}Pb apparent flux obtained from lake sediments can be altered by redistribution of sediments or by differences in sediment type or grain size. (TUREKIAN *et al.*, 1977)

The atmosphere-born nuclides may fall onto the surface of a water body or onto its catchment. ^{210}Pb and ^{210}Po falling onto soils are irreversibly scavenged by soil particles, and the only method by which they can be lost to the catchment is via soil erosion (LEWIS, 1977; DOMINIK *et al.*, 1987). DOMINIK *et al.* (1987), calculated the catchment area residence time for ^{210}Pb in the Alpine Rhone to be ~1500 years. The eroded particles are transported via run-off and rivers to the water body. Which mechanism delivers the most ^{210}Pb and ^{210}Po to a particular water body depends on the ratio of catchment area to surface area. Additionally ^{210}Pb is formed in the water column by decay of ^{226}Ra.

Plankton take up and concentrate dissolved radionuclides from natural waters, and studies of marine food chains have shown a progressive bio-accumulation of radionuclides (KHARKAR *et al.*, 1976; HEYRAUD *et al.*, 1976; SKWARZEC & FALKOWSKI, 1988). These studies have shown that the natural decay series nuclides are preferentially enriched in the order: Po >> Pb = Th > Ra > U.

Laboratory uptake experiments have explained this observation (FISHER *et al.*, 1983; FISHER et al., 1987) which is illustrated in **Table 1.3.2.** Once uptaken by phytoplankton ^{210}Pb is associated with structural components of the cell, such as cell walls, which are difficult for herbivorous zooplankton to assimilate. In contrast ^{210}Po associates with cellular organic compounds which are assimilated by zooplankton. Consequently zooplankton faecal matter contains relatively more ^{210}Pb.

Table 1.3.2. Bio-concentration of ^{210}Po relative to ^{210}Pb in the marine food chain. From FISHER *et al.* (1983).

substance	**^{210}Po/^{210}Po activity ratio**
phytoplankton	4.6
zooplankton	26.7
crustaceans	131
zooplankton faecal matter	2.3

Sinking plankton and their debris have been estimated to account for most of the natural decay series nuclides sedimenting out of oceanic surface waters (BEASLEY *et al.*, 1978; FISHER *et al.*, 1987). In typical oceanic waters (e.g. BACON *et al.*, 1976), there is a deficit of dissolved ^{210}Po relative to dissolved ^{210}Pb in the mixed layer (0-50 m), suggesting rapid biological removal, and an excess of dissolved ^{210}Po over its parent in thermocline waters (100-300 m), suggesting regeneration of dissolved ^{210}Po following degradation of planktonic debris.

This ^{226}Ra-^{210}Pb-^{210}Po disequilibria has been used to investigate particle scavenging in the open ocean (COCHRAN *et al.*, 1983; CHUNG, 1987; RITCHIE & SHIMMIELD, 1991; THOMSON *et al.*, 1993; SHIMMIELD & RITCHIE, 1994) and the coastal marine environment (SANTSCHI *et al.*, 1979; LI *et al.*, 1981; TANAKA *et al.*, 1983; NOZAKI, 1991; NOZAKI *et al.*, 1991; KADKO, 1993; WEI & MURRAY, 1994).

^{210}Pb has been widely used to determine sediment accumulation rates in the coastal marine (CARPENTER *et al.*, 1982), fjordic (MATSUMOTO & WONG, 1977; SKEI & PAUS, 1979; SMITH & WALTON, 1980; SKEI, 1983) and lacustrine environments (DAVIES *et al.*, 1984; OLDFIELD & APPLEBY, 1984; WAN *et al.*, 1987; EDGINGTON *et al.*, 1991), as well as in salt marshes (ZWOLSMAN *et al.*, 1993) and river water-meadows (PETIT *et al.*, 1987).

There are two main models used to determine accumulation rates. In the constant initial concentration model (CIC) of ROBBINS & EDGINGTON (1975) there are four assumptions that must be made: 1) the flux of ^{210}Pb to the sediment is constant; 2) the sediment accumulation rate is constant; 3) the supported ^{210}Pb activity can be

determined from the sediment ^{226}Ra activity; 4) there is no post-depositional mobility of ^{210}Pb.

The CIC model utilises a form of the general radioactive decay equation:

$$\ln A_y = \ln A_o - \lambda t \qquad \textbf{Eqn. 1.3.1.}$$

where A_y = activity of excess ^{210}Pb at depth y
A_o = initial activity of excess ^{210}Pb at the surface
λ = ^{210}Pb decay constant
t = time in years which is equivalent to z / w , where:
z = weight of sediment per unit area (g cm^{-2})
w = sediment accumulation rate (g cm^{-2} y^{-1})

the equation can be rewritten as:

$$\ln A_y = -(\lambda/w) + \ln A_o \qquad \textbf{Eqn. 1.3.2.}$$

which is in the form y = mx + c, therefore by plotting ln A versus z and calculating the gradient, the sedimentation rate can be calculated from $w = -(\lambda/m)$.

The constant rate of supply (CRS) model of APPLEBY & OLDFIELD (1978) can be used when there is a change in sedimentation rate down the core. It assumes that the flux of excess ^{210}Pb supply to the sediment is constant with time. The age, t_i, at the base of a depth horizon is calculated from:

$$t_i = (1/\lambda) \ln (A_o/A_i) \qquad \textbf{Eqn. 1.3.3.}$$

where λ = ^{210}Pb decay constant
A_o = total cumulative excess ^{210}Pb (i.e. integrated throughout whole core)
A_i = cumulative excess ^{210}Pb below interval i

The sedimentation rate can be determined by dividing the cumulative sediment weight per unit area by the age of interval i. OLDFIELD AND APPLEBY (1984) suggest that each method should be considered for each case, to see which gives the best results.

^{210}Pb has also been used to track sedimentation particle pathways and sediment mixing, via its determination in coastal sediment cores (BENNINGER *et al.*, 1979; BENNINGER & KRISHNASWAMI, 1981; NITTROUER *et al.*, 1984; CARPENTER *et al.*, 1984; BUESSELER *et al.*, 1985/6; HELZ *et al.*, 1985/6).

1.4. Radionuclide Mobility in Low-Oxygen Environments

Natural and man-made radionuclides, have been widely used in the dating of lacustrine and near-shore environments; ^{210}Pb dating is the most widely used (e.g. MATSUMOTO & WONG, 1977; EDGINGTON *et al.*, 1991). ^{210}Pb dating is important in determining the history of anthropogenic pollution (e.g. GOLDBERG *et al.*, 1979; FARMER, 1983). In recent years, a number of researchers have found ^{210}Pb dates disagreeing with those of other methods, and consequently the assumptions of the ^{210}Pb dating models have been questioned, especially the post-depositional mobility of ^{210}Pb. In addition should man-made radionuclides currently locked in sediments be remobilised and released to the water column and hence the food chain it may represent a pollution problem. Also radionuclides are used as tracers of particle-reactive anthropogenic pollutants, and it is necessary to understand their aquatic chemistry. This section will summarise the evidence for and against the post-depositional mobility of ^{210}Pb and other particle-reactive radionuclides.

The agreement between ^{210}Pb dating and other methods is generally taken as evidence of non-mobility. APPLEBY *et al.* (1979) found ^{210}Pb dates agreeing with varve chronology in three Finnish lakes, as did CRUSIUS & ANDERSON (1990) in the Experimental Lakes Area. In Framvaren Fjord, Norway, where 38 cm of marine sediment were laid down in 150 years since dredging opened a channel to the sea, SKEI (1983b) found a ^{210}Pb-derived accumulation rate of 0.3 cm yr^{-1}. In the Saguenay Fjord, Quebec, ^{210}Pb dating was in agreement with pollen stratigraphies and ^{137}Cs dates (SMITH & WALTON, 1980). In Drammensfjord, Norway, ^{210}Pb dating of an increase in C_{org} content was consistent with the commencement of paper production in the catchment area (SCHAANNING *et al.*, 1988).

Many researchers have found discrepancies between ^{137}Cs and ^{210}Pb dates. DAVIES *et al.* (1984) attributed the difference to "a failure of ^{137}Cs dating" in New England and Scandinavian soft-water lakes. In Griefensee, Switzerland, WAN *et al.* (1987) attributed it to ^{210}Pb mobility, as did ERTEN *et al.* (1985) for cores taken from Lake Zurich. In Loch Etive, RIDGWAY & PRICE (1987) found ^{137}Cs accumulation rates faster than those for ^{210}Pb, and attributed this to Pb mobility. However when O'DONNELL (1987) recalculated the sedimentation rates using the onset of the ^{137}Cs peak rather than the first appearance of ^{137}Cs, he obtained accumulation rates equal to those from ^{210}Pb dating. He attributed the downward mobility of ^{137}Cs to a combination of bio-mixing and diffusion. SHIMMIELD (1993) also made a separation between ^{137}Cs-depth-of-penetration dates and ^{137}Cs-maxima dates in Loch Etive cores; in all cores the former produced faster sedimentation rates. She found that ^{137}Cs-maxima dates were in agreement with ^{210}Pb dates in those cores where continuous accumulation applied; in those cores where an increase in sedimentation rate towards the surface was apparent there was significant disagreement.

^{210}Pb and Pb mobility has been postulated from other marine evidence. KOIDE *et al.* (1973) found a sub-surface maxima in ^{210}Pb solid-phase activity in Santa Barbara Basin, off California, and attributed this to Pb-sulphides precipitating in the anoxic zone, forming a concentration gradient in the pore water, leading to downward mobility. GAILLARD *et al.* (1986) interpreted pore water Pb concentrations higher than the overlying water in Villefranche Bay, as evidence of remobilisation of Pb. GOBEIL & SILVERBERG (1989) observed a double Pb concentration peak in the pore waters of Laurentian Trench sediments, and attributed the top peak to release of Pb during aerobic organic matter degradation, while the bottom peak suggested that Pb followed the Fe redox cycle. RIDGWAY & PRICE (1987) found a strong correlation between I/C_{org} ratios and Pb/Al ratios. Since the change in the I/C_{org} ratio with depth is due to the release of I from degrading organic material, they attributed this to Pb release from degrading organics.

There is also evidence for ^{210}Pb mobility in lakes. In a comprehensive time-series study of seasonally anoxic Bickford Pond, Ma, (BENOIT & HEMOND, 1987, 1990, 1991), a mass balance model revealed an increase in bottom water ^{210}Pb and ^{210}Po activities as anoxia developed that correlated with the increase of Mn and Fe. When the water column overturned, and the water became oxygenated again, the Fe and Mn was oxidised and precipitated out rapidly scavenging the radionuclides from solution

again. In a similar time-series study in Crystal Lake, Wi, (TALBOT & ANDREN, 1984), ^{210}Po was released to the water column, but ^{210}Pb was not.

Some researchers have devised experiments to determine ^{210}Pb and other radionuclide mobility. In microcosm experiments SANTSCHI *et al.* (1983), found that "the mobility of the geochemical tracers ^{210}Pb, ^{234}Th, ^{228}Th and $^{239+240}$Pu is controlled predominantly by affinity towards particles and by the movement of the particles themselves." To evaluate radioactive waste disposal possibilities COLLEY & THOMPSON (1990) determined the activities of U decay series nuclides across two U-rich turbidites, deep in Madeira Abyssal Plain sediments. The presence of secular equilibrium between the mother-daughter pairs indicated non-mobility, and therefore ^{234}U, ^{230}Th and ^{210}Po were adjudged to be immobile, while only a fraction of ^{226}Ra was mobile. CRUSIUS & ANDERSON (1991) determined ^{210}Pb above and below a turbidite of low ^{210}Pb activity in Black Sea sediments, and found no diffusion of ^{210}Pb even though the waters overlying the sediment are anoxic and sulphide-bearing.

There has been similar discussion of $^{239+240}$Pu mobility, and some aspects of the discussion have relevance to the natural radionuclide mobility discussion. ALBERTS & ORLANDI (1981) noted that if only 1% of the $^{239+240}$Pu sedimentary inventory in Par Pond was released, the bottom water activity would be 100 times the measured level. Since 36% of the Mn inventory was released during anaerobic conditions, they stated that there was no release of $^{239+240}$Pu. SHOLKOVITZ *et al.* (1982), found a five-fold increase in $^{239+240}$Pu activities in the Mn and Fe rich bottom waters of seasonally anoxic Gull Pond, MA, and attributed this to Pu release from the sediments. In a pond which underwent seasonal anoxia, where the Fe and Mn concentration of the bottom water rose 230 and 16 times respectively, ALBERTS *et al.* (1986), found a two-fold increase in $^{239+240}$Pu bottom water activities during anoxia. The surface $^{239+240}$Pu activities dropped however, and the inventory stayed the same. The increase in $^{239+240}$Pu was thus a change in storage effect. BUESSELER *et al.* (1985) reported a seasonal variation in pore water $^{239+240}$Pu activities in Gull Pond. In June the pore waters contained high activities of $^{239+240}$Pu, with a peak at a depth of 5 cm, while in August the activities were close to zero. Since Fe and Mn showed similar profiles, albeit with less drastic seasonal differences, release of Pu linked to the Fe and Mn redox cycle is possible, although the authors note that the flux of any such release would be insufficient to make any impact on the sedimentary Pu inventory.

In marine cores taken from the northeast coast of the USA, LIVINGSTON & BOWEN (1979) found the $^{239+240}Pu/^{137}Cs$ ratio decreasing with depth and attributed this to "a complicated bioturbational process moving the nuclides, together, down into the sediments, of chemical resolubilisation, at depth, of plutonium only, and of its subsequent upward translocation in the interstitial solution." Since reduced Pu is insoluble, its solubility was explained by a Pu-organic complex. "Some re-immobilisation of plutonium near the surface is implied, and a mechanism is suggested for this, based on displacement of plutonium from organic complexes by the increasing concentrations, in upper layers of the sediment, of re-oxidised dissolved iron." ^{137}Cs was postulated to be immobile in the sediment cores. Part of this argument is that since anoxic sediments contain high organic concentrations, they will have the most mobilisation and therefore these sediments will have a near absence of Pu. CARPENTER & BEASLEY (1981), however, reported the presence of $^{239+240}Pu$ in the anoxic sediments of Saanich Inlet, the Cariaco Trench and the Golfo Dulce, an anoxic basin off the Pacific coast of Costa Rica. They found that the inventories were in agreement with those predicted from fallout and presented this as evidence against remobilisation. In laboratory and field studies in Buzzards Bay, MA (SHOLKOVITZ *et al.*, 1983; SHOLKOVITZ & MANN, 1984), $^{239+240}Pu$ and ^{137}Cs were determined in pore waters, the results showing that there is preferential downward transport of ^{137}Cs and that $^{239+240}Pu$ is immobile in coastal sediments.

MALCOLM *et al.* (1990) determined $^{239+240}Pu$ and ^{241}Am activities in the solid and aqueous phases of cores taken from the Irish Sea, near the Sellafield outlet pipe. Although there were maxima in the pore water activities of both nuclides, these peaks occurred at different depths (and hence were considered not to be associated with) any of the major diagenetic indicators. Furthermore the $^{239+240}Pu$ and ^{241}Am peaks were found to be increasing in depth with time, at the same rate as the peaks in the solid phase (the solid phase peaks are due to the Sellafield discharge record). Since the depth of diagenetic peaks such as the Fe and Mn peaks stay constant with time, an equilibrium adsorption-desorption mechanism was postulated. The distribution coefficient (K_d , defined as solid activity/dissolved activity) was calculated and there was found to be a small, systematic variation in K_d with depth for both nuclides. This suggested that the solid and aqueous phases were slightly out of equilibrium, and MALCOLM *et al.* (1990) suggested that this was "most likely to be explained by a combination of the relative kinetics of adsorption and desorption together with differential rates of interstitial water irrigation and sediment particle mixing".

1.5. Rationale for study

Naturally occurring, particle-reactive radionuclides, can be used to predict the behaviour of particle-reactive anthropogenic pollutants in the coastal marine environment. This study will attempt to follow the cycles of the natural radionuclides ^{210}Pb and ^{210}Po, in the coastal marine environment, from river to sediment. Of particular importance will be their partitioning between the particulate and dissolved phases in the water column, and their sedimentation through the water column. The magnitude and rate of each process will be estimated, using simple box-models.

The study will also attempt to determine whether ^{210}Pb and ^{210}Po are diagenetically mobile in anoxic sediments. Any post-depositional mobility of radionuclides in sediments may cause the dating of these sediments in pollution history studies to be inaccurate. ^{210}Pb in particular is suspected of possible mobility in oxygen-poor environments and it is important to ascertain the extent of such mobility. In addition should the particle-reactive man-made radionuclides be released to the environment by reductive remobilisation, they could be introduced to the food chain which could cause potential health problems.

There is also concern that increasing fluxes of organic detritus due to the introduction of fish and mussel farming to Scottish West coast sea lochs, may cause lower oxygen conditions, which may in turn have an increased mobilisation effect on the radionuclides. Loch Etive is a well-characterised sea loch, with low-oxygen conditions in the deep water, where the farming of fish and mussels takes place, and where ^{210}Pb mobility is previously suspected (RIDGWAY & PRICE, 1987).

Many natural processes significantly change with season. ^{210}Pb and ^{210}Po inputs via rainfall and hence river flow are extremely variable (e.g. BASKARAN *et al.*, 1993) and this should be reflected in the water column processes. An additional complication is provided by varying types and numbers of particles found at different times of the year. This study will attempt to determine which types of particles ^{210}Pb and ^{210}Po are associated with, and whether this changes with season.

Chapter 2 : Environment And Method

Part One: Environmental setting of Loch Etive

2.1 Introduction and Geography

Loch Etive is a typical sea-loch (fjordic estuary) on the West coast of Scotland, 5 km north of Oban and 90 km north-west of Glasgow (**Fig. 2.1.1**). In common with other fjords it is long (28 km), compared to its width, has steep sides, and a right-angled bend. An entrance sill, 4 km long, less than 10 m deep and 240 m wide connects the loch to the Firth of Lorne, which separates Mull and Ardnamurchan from the mainland. Severe shoaling on the sill chokes currents, so that the internal tidal range is 2 m, compared to an external range of 4 m (EDWARDS & EDELSTEN, 1977). A further shallow sill (depth 13 m) at Bonawe, divides the Loch into two roughly equal parts (**Fig. 2.1.2**). The outer basin has a maximum depth of 62 m, runs east to west through low hills, and is further separated by a sill at Achnacloich. The inner, deep, basin has a maximum depth of 145 m, and runs north-east to south-west through more mountainous terrain. The rainfall catchment area of 1350 km^2 is the largest of any Scottish fjord (**Fig. 2.1.1**) (EDWARDS & SHARPE, 1991). Contrary to regional south-westerly drainage, water from the neighbouring freshwater, Loch Awe catchment drains north-westward through the Pass of Brander to enter Loch Etive at the Bonawe narrows. The other major freshwater inputs are the River Etive which drains into the head of the loch, and the River Kinglass, which drains into the deep basin.

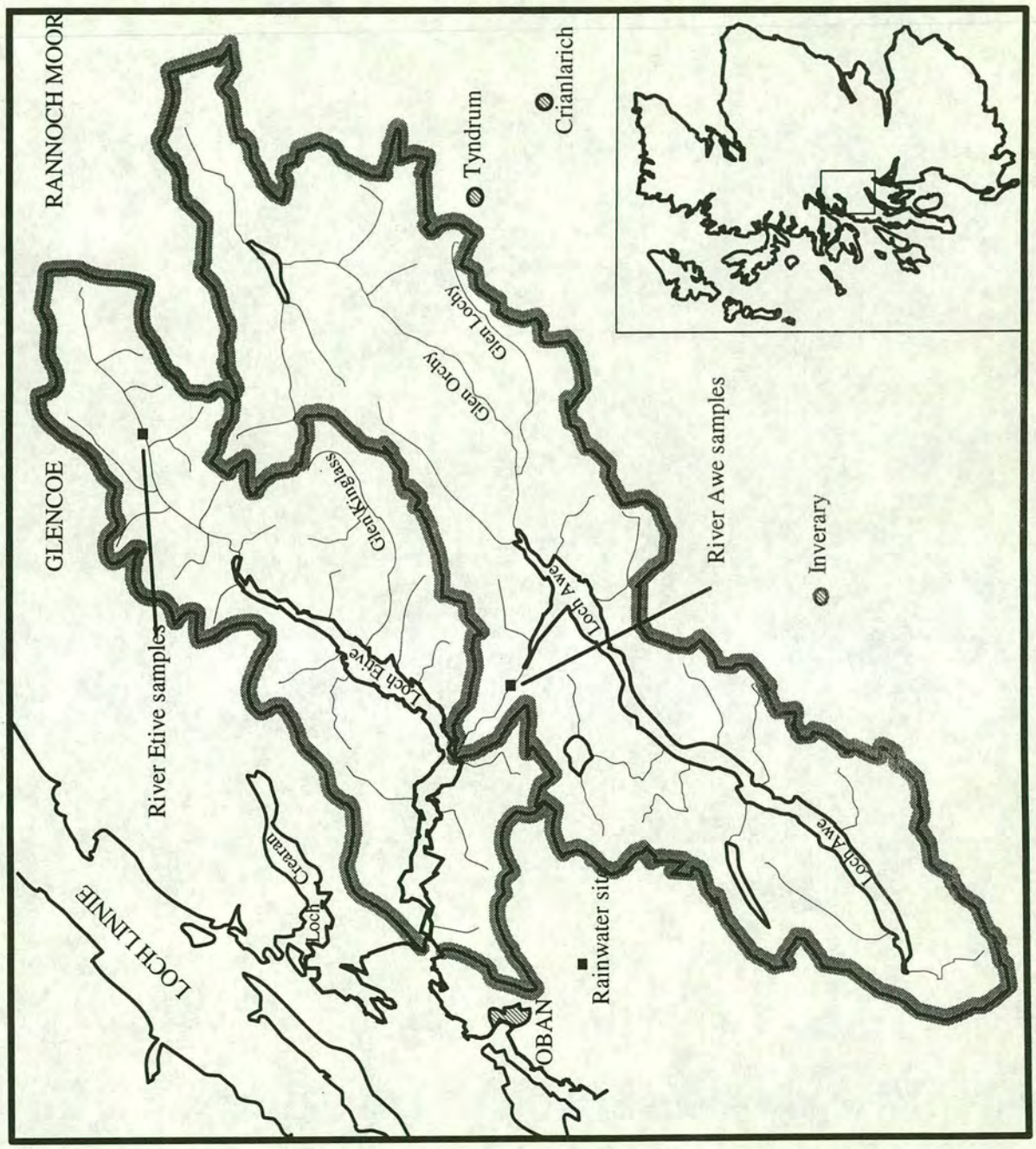


Figure 2.1.1. Loch Etive catchment area is composed of the Loch Awe catchment (63 %); the River Etive catchment (11 %); River Kinglass catchment (6 %); and other streams and rivers emptying into Loch Etive (19 %). Inset map of Scotland.

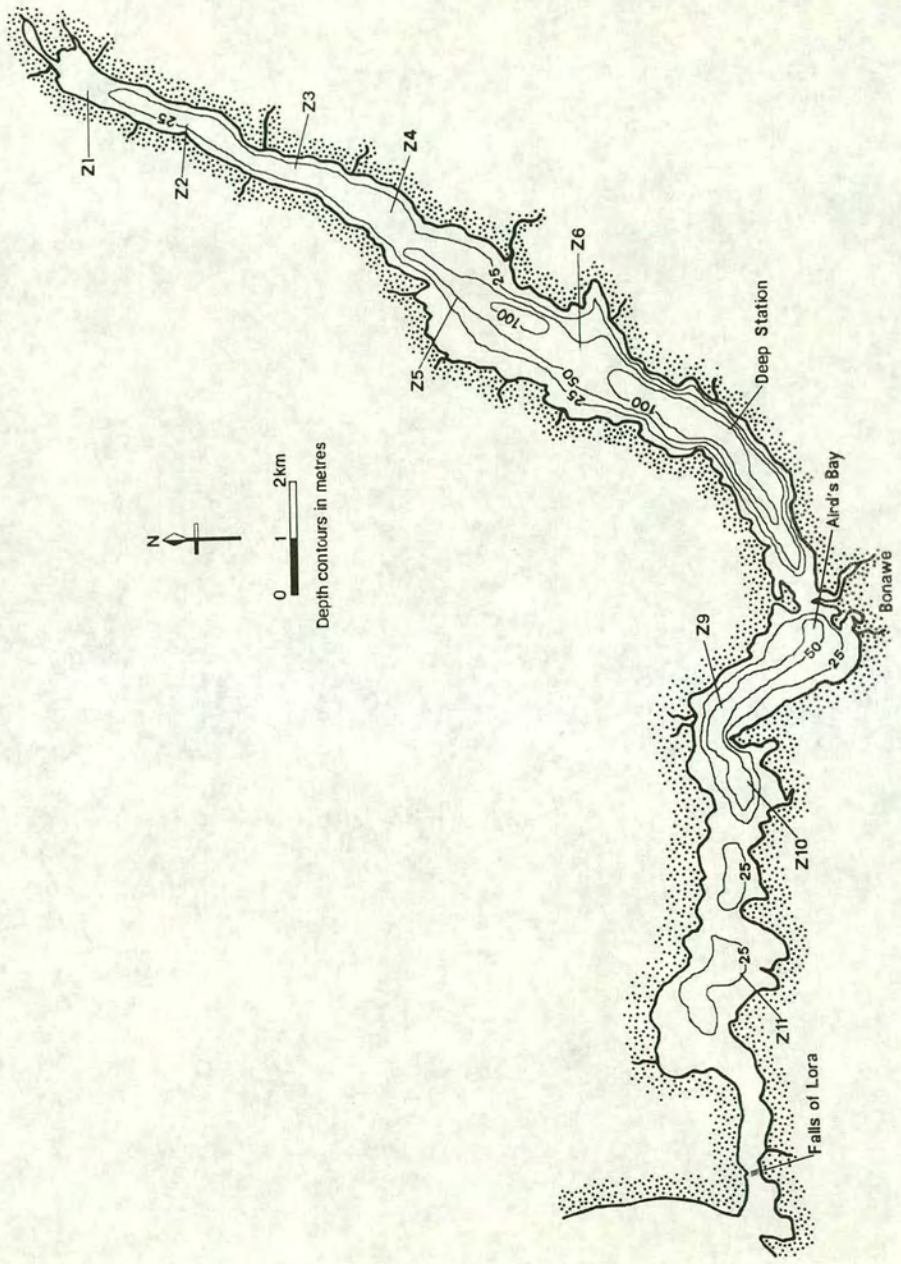


Figure 2.1.2. Bathymetry of Loch Etive, showing core sampling sites.

The geology of the Loch Etive catchment is shown in **Figure 2.1.3.** The outer basin runs through Devonian andesitic and basaltic lavas and tuffs, which form low rolling hills which continue northwards to Loch Creran and southwards to Loch Avich (O'DONNELL, 1987). The inner basin runs through the mountainous Glen Coe-Etive Granite, among the youngest of the Caledonian ring-complexes, post dating the final major Caledonian folding (PANKHURST & SUTHERLAND, 1982). There are three main concentric granite bodies in the complex, which decrease in acidity with age. The complex is bordered by faults. One runs NW-SE through the pass of Brander and continues NW along Glean Salach to Loch Creran. The second runs NE-SW and continues along the length of Loch Awe (O'DONNELL, 1987). The Awe catchment is composed of Dalradian regional metamorphics: slates, phyllites, quartzites and quartz schists and epidiorite schists are common.

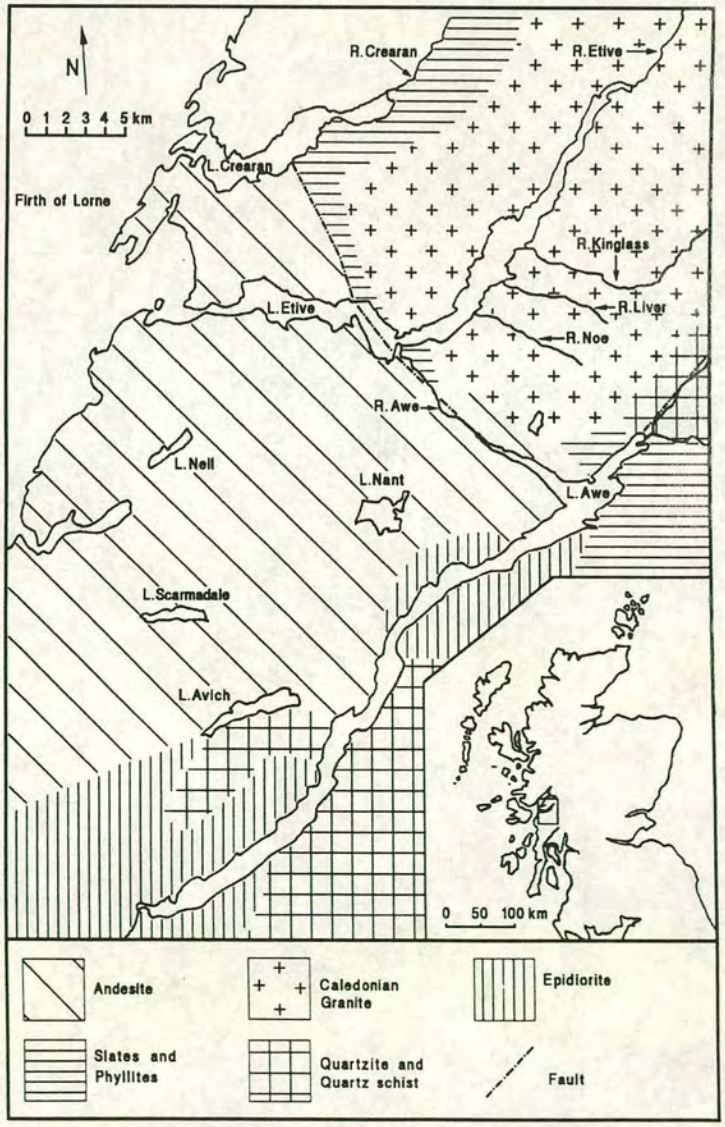


Figure 2.1.3. Geology of the Etive catchment (after RIDGWAY, 1984, and O'DONNELL, 1987).

2.2 Hydrography

The prevailing Atlantic south-westerlies, and the proximity of high mountains results in an extremely high rainfall with the wettest months being September to January, and the driest May. The mean (30 year) annual rainfall for the Etive catchment is 2197 mm (O'DONNELL, 1987). The combination of large catchment area and high rainfall results in a huge freshwater input to the loch. Since 1963 the River Awe flow has been regulated by a hydro-electric scheme, which provides weekly figures for run-off (n) from the Awe catchment to Loch Awe and River Awe discharge (j) into Loch Etive. The run-off varies between 0-130 Mm^3 $week^{-1}$ and the discharge between 10-160 Mm^3 $week^{-1}$. Because of the proximity, similar topography, ground cover and height of the two catchment areas EDWARDS & EDELSTEN (1977) assumed that the hydrologic responses of the two areas are the same, and thus the total freshwater flow into Loch Etive is given by:

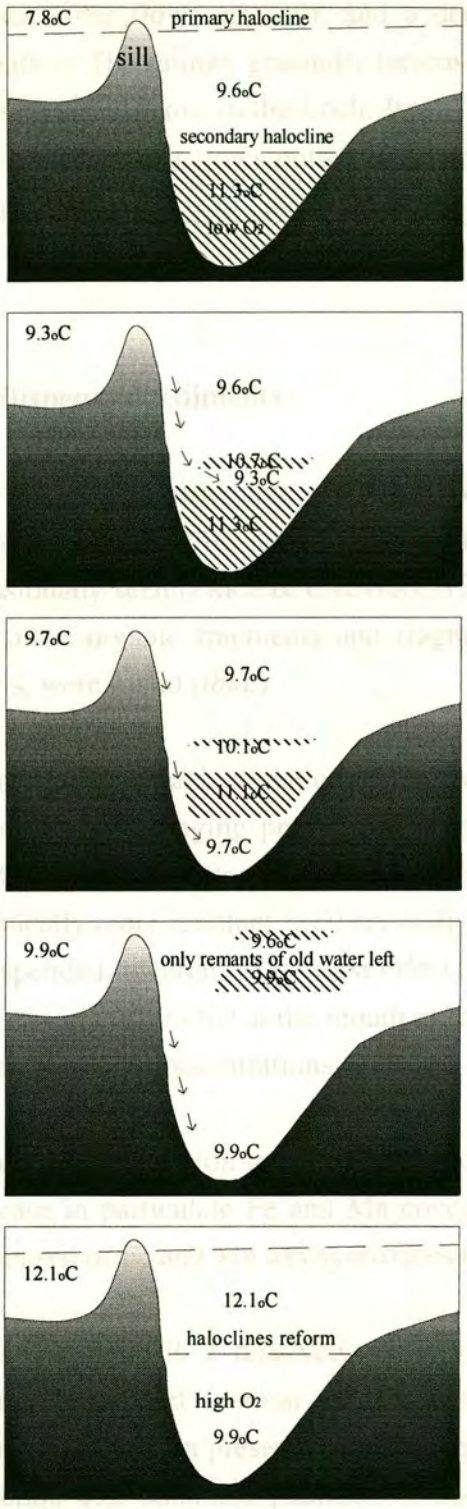
$$f = j + nE/A \qquad \textbf{Eqn. 2.3.1.}$$

where E and A are the catchment areas of Loch Etive, and Loch Awe respectively, in km^2, j is the discharge into Etive from the Awe catchment, in Mm^3 $week^{-1}$, and n is the run-off from the Awe catchment, in Mm^3 $week^{-1}$. The Awe flow is thus usually 63 % of the total input, which varies between 20-260 Mm^3 $week^{-1}$.

The huge input of fresh water exerts considerable influence on the hydrography of Loch Etive. A brackish (salinity 3-20 ‰) cap extends the length of the loch to a depth of 2.5-10 m. The combination of this cap and low tidal energy causes intense density stratification in the inner basin, with a secondary pynocline below sill depth. The bottom water stagnates for months or years, characterised by depleted dissolved oxygen concentrations and increased nutrient concentrations. Gradual diffusion across the pynocline slowly changes the temperature and lowers the salinity (by about 0.05 ‰ a month), and hence the density falls preparing the system for aperiodic renewals. These occur when the water in Aird's Bay at sill level is sufficiently dense to overflow the sill and replace inner basin bottom water of lower density. There are many mechanisms for the renewal of fjordic bottom water, most being extra-fjordic, e.g. high density water at sill level is formed by coastal upwelling or by changes in wind patterns. Intra-fjordic mechanisms are rarer, e.g. the salinity of the fjordic compensation current rises in relation to an increase in run-off.

EDWARDS & EDELSTEN (1977), described another mechanism for Loch Etive, entirely dependent on run-off. After an extended period of low run-off the Aird's Bay water at sill depth becomes progressively more marine and hence dense. The flushing time for this water is four weeks and this is the response time of the renewal mechanism to changes in run-off which are the main cause of the sill density fluctuations, temperature variation accounting for only 10 %.

There are three phases in a renewal: (1) stagnation of bottom water, while its top is eroded by sill water, (2) overflows of sill water and (3) restagnation of newly formed bottom water. Representative sections are illustrated in **Fig. 2.3.1.** In the first two diagrams there are three water bodies with steep vertical gradients in temperature, salinity and dissolved oxygen between them. Below the secondary pynocline the stagnant bottom water (70-150 m) is low in oxygen, and higher in temperature and salinity than the well-mixed sill-derived middle water (10-60 m) above it. The overflows of sill water that form this body erode the top of the stagnant water lowering the secondary pynocline. The primary pynocline separates the middle water from the brackish surface water (0-10 m), the temperature and salinity of which is very variable depending on climatic conditions. After an extended period of low rainfall the density of the sill water can be greater than the deep water and renewal occurs as shown in pictures 3 and 4. During spring tides overflowing sill water forms dense turbulent plumes which flow down the slope of the basin, to a level determined by their density. It is possible that the water carries surficial sediment from the slope to the deep basin. The old water is diluted by mixing and lifted upwards to sill level. In this case the old water is of higher temperature and it is possible to follow the remnant water. From the volume of the basin (450 Mm^3) and the volume of inflow each tide (mean 30 Mm^3), the minimum time to completely flush the basin is one week. Renewal continues as long as the run-off remains low, as the surface water gradually increases in temperature, so this is reflected in increasing bottom water temperature. When the run-off increases again the density of the sill water decreases and the newly formed bottom water is isolated and restagnates. Since most renewals take place in the low rainfall late spring or early summer the bottom water generally has a fairly high temperature, and thus in winter when the intermediate layer is cold there is a temperature inversion in the Etive deep basin.



A Stagnation:
high run-off, strong haloclines

B Erosion:
low run-off, renewals to 70-80m

C Renewal:
extended low run-off, deep renewal

D Renewal:
extended low run-off, deep renewal

E Restagnation:
high run-off, deep water isolated

Figure 2.2.1. Stages in renewal of bottom water in Loch Etive: (a) stagnation; (b) erosion; (c) & (d) renewal; (e) restagnation.

1973). The geochemical composition of plankton in a transect of Loch Etive was measured by MALCOLM (1981), and the following concentrations were found: C_{org}, 18-30 wt.%; N, 3.9-5.8 wt.%; Mn 43-89 ppm; Fe 0.4-1.5 wt.%; Cu, 34-51 ppm; Zn, 187-332 ppm; Pb, 13-22 ppm. The C/N ratio of Loch Etive plankton was found to be 4.8-5.7 with a mean value of 5.2. OVERNELL & YOUNG (1995) found a similar value of 4.7 outside Loch Etive in outer Loch Linnie.

2.4 Sediments

The mineralogy of the bottom sediment is similar to that of the SPM (PRICE & CALVERT, 1973), and contains minerals which are typical of mechanical weathering in a temperate climate (O'DONNELL, 1987). Sediment in the deep basin is mainly composed of clays (illite, muscovite and chlorite) with lower amounts of feldspars (mostly albite) and quartz. The surface sediment from Aird's bay is similar to the deep basin, but appears to show a slightly higher quartz and feldspar content. The mineralogy of O'DONNELL's (1987) cores was relatively constant at depth, suggesting no major changes in lithology or accumulation. These cores contained less calcite than was found in cores from other local sea lochs, which also showed marked changes in mineralogy at depth, suggesting discontinuities.

The two basins show different sediment types. Although the surface in each basin is red-brown, oxidised sediment, the thickness of this layer changes. In the outer basin the oxidised layer is 5 cm thick, and abundant in macrofaunal presence, mainly worms, with occasional bivalves (RIDGWAY & PRICE, 1987). This overlies greenish-grey sediment containing low levels of organic matter, and variable levels of calcium carbonate, some of which is mollusc debris (PRICE & CALVERT, 1973). In the inner basin the oxidised layer is less than 1 cm thick, enriched in Fe and Mn, and overlies dark green-grey to black reducing sediment, containing high levels of organic matter and very small quantities of $CaCO_3$. Faunal activity is more restricted than in the outer basin, although some worm tubes are reported.

There is considerable variation in the surface sediments in a transect of the loch. Organic carbon content increases landward, with distinct minima at river mouths indicating dilution by detrital material (WILLIAMS *et al.*, 1987). The C/N ratio also

increases landward from 7.3-14.2. Taking the 'marine' source to have a C/N ratio of 5.2 (see 2.3.) and the 'terrigenous' source 17.3 from measurement of River Etive SPM, MALCOLM & PRICE (1984) separated out the 'marine' carbon component of the total C_{org} content, and found good correlation between this and I and Br concentrations. Surface Mn concentration rises from low values (0.04 wt.%) at either end of the loch to huge values in the deep basin, reaching a maximum of 4 wt.% (WILLIAMS *et al.*, 1987). The surface activities of various radionuclides was also determined by WILLIAMS *et al.* (1987). Excess ^{210}Pb follows the C_{org} content, indicating either chemical association with organics or common dilution. ^{232}Th surface activity decreases seaward, indicating a fall-off in terrigenous weathered material, while ^{228}Th surface activity follows that of Mn in showing an enrichment in the deep basin. The manmade radionuclide activities increase seawards indicating the source of these nuclides to be Sellafield waste.

2.5 Population and Industry

The relative remoteness, and the harsh topography of the Highlands results in a very low population. The nearest towns to Loch Etive are Oban, 5 km to the south and Fort William, 45 km to the North, both with a population of around 10 000. On the shores of the outer basin of Loch Etive are three villages: Connel, Taynuilt and Bonawe, with a collective population of around 8 000, while aside from a few crofts the shore of the inner basin is uninhabited. The River Etive and Kinglass catchments also drain very sparsely populated areas, while the Awe catchment includes several small villages. The major land uses are forestry, sheep farming and tourism. Fishing is an important industry for the local population, and there is a trout farm at Bonawe, and mussel harvesting is extensive in Loch Etive. At the Bonawe narrows there is a quarry producing gravel for road-construction. There are no major industries in the area - the nearest industrial centre is Glasgow 90 km to the south-east. However heavy metal pollutants are transported atmospherically, and deposited in Loch Etive. After studying stable Pb isotope ratios SHIMMIELD (1993) reported the presence of petrol additive derived Pb in Loch Etive sediments. In conclusion, aside from the radioactive effluent emanating from Sellafield, Loch Etive is a generally pristine environment in which to study natural processes.

Part Two: Sampling strategy and methods

2.6. Introduction

An integrated monthly sampling regime was designed to sample one site in detail over the course of a year. Previous studies have shown that there is little or no horizontal variation in the deep basin of Loch Etive (EDWARDS & EDELSTEN, 1977; EDWARDS & GRANTHAM, 1986), so one station can be used to represent the whole basin. A permanent buoy moored in the centre of the deep basin in about 120 m of water was chosen (N 56 27 45; W 05 11 13) and is henceforth called deep station. The actual depth at this buoy varied a great deal from month to month, presumably due to different directions of currents and winds swinging the research vessel away from or closer to the shore in an area with a steep bottom slope. In addition to a suite of samples to be taken monthly or quarterly, sediment traps were to be deployed continuously and sampled monthly and associated one-off samples were taken occasionally at the deep station and at other sites. After one year of sampling it was decided to continue the study for another 6 months, to fill in the gaps in the record, e.g. there were two sampling hiatuses in the sediment trap record and to have ancillary information e.g. rain and river water samples, for the same months as the water column samples.

2.7. Water

Temperature and salinity measurements were made on the downward part of a CTD (conductivity-temperature-depth) cast monthly, at the deep station. Generally the depths that readings were taken at were every metre for 0-10 m, every 2 m for 10-20 m and every 5 m for the remainder of the water column. In regions with high vertical gradients, the frequency of readings was increased. The CTD also has an oxygen electrode and a current direction and strength meter. Density was estimated from temperature and salinity using the polynomial expression given in FOFONOFF & MILLARD (1983, see **A1.1.**). Deep water samples were collected monthly by multiple castings of polythene NIO bottles, and transferred to 20 litre polythene carboys for radiochemical analysis in the particulate and dissolved phases, with samples for nutrient and dissolved oxygen analyses reserved. All containers were rinsed out with small aliquots of sample.

A stand-alone pump (SAP) was deployed at depth quarterly. This filters, in-situ, large volumes (80-200 l) of water through 0.45 μm Azypor filters in parallel, and MnO_2 coated wound polypropelene cartridges in series, for radiochemical analysis in the particulate and dissolved phases.

After eight months of sampling it was recognised that the radionuclide inputs into Loch Etive would need to be characterised and thus River Etive or Awe water was collected bi-monthly by emersing carboys in the water and rain water was collected monthly via run-off of an aluminium greenhouse roof into a carboy. The frequency of water sampling is shown in **Table 2.7.1.**

Table 2.7.1. Frequency of water sampling from the deep basin of Loch Etive 1990-1993, and parameters determined in the samples.

	deep water samples				**river**	**rain**	**SAP**	
date	$^{210}Pb/^{210}Po$	nutrients	chloro-phyll	SPM	$^{210}Pb/^{210}Po$	$^{210}Pb/^{210}Po$	$^{210}Pb/^{210}Po$	gamma
21/11/90	YES	YES						YES
20/12/90	YES	YES						
6/ 2 /91	YES	YES						
22/ 3 /91	YES	YES						YES
18/ 4 /91	YES	YES						YES
22/ 5 /91	YES	YES						
18/ 6 /91	YES	YES					YES	YES
17/ 7 /91	YES	YES						
13/ 9 /91	YES	YES					YES	YES
14/10/91	YES	YES			Both			
13/11/91	YES	YES						
12/12/91	YES	YES			Etive			
24/ 2 /92	YES	YES	YES			YES		
23/ 3 /92						YES		
24/ 4 /92	YES		YES		Awe	YES		
28/ 5 /92	YES	YES	YES		Etive	YES		
20/ 6 /92	YES	YES	YES		Etive	YES		
25/ 3 /93				YES				

2.8. Sediment traps

Of key importance in the understanding of marine cycling processes is the determination of the composition and quantity of settling particles. Sediment traps, containers open at one end and suspended at depth for time periods in the order of weeks, intercept and concentrate falling particles. They are particularly suited to the coastal marine environment, due to: increased rain of particles near the coast, from river run-off and primary production; the ease and safety of mooring in shallow, sheltered waters; and the ease of revisiting trap mooring sites on short time periods leading to good time-series data.

There are many designs of sediment trap (GARDNER, 1980a, DYMOND *et al.*, 1981), these do not simply catch particles falling vertically through the water column, since the particle fall velocity is usually small compared to horizontal current velocity. The sediment is instead collected by a process of fluid exchange, where the trap geometry, aspect (height/diameter) ratio and the current speed control the residence time of water inside the trap, and hence the trapping efficiency. Generally cylindrical traps (providing the aspect ratio is greater than 3:1 and the internal diameter is greater than 4 cm) produce a vertical flux closest to the true value in all conditions. Conical (funnel) traps generally underestimate (undertrap) the true value in turbulent conditions, although the placement of a grid (or "baffle") in the mouth of the trap reduces turbulence across the mouth, and increases the residence time of water in the trap. Traps with necks narrower than their bodies overtrap at an unpredictable rate, and the composition of the sediment collected is biased towards fine grained particles (HÅKANSON *et al.*, 1989; GARDNER, 1980a, 1980b). Other important trap design points are that the traps should be kept vertical, as any inclination may cause a change in trapping efficiency (GARDNER *et al.*, 1985); the traps should be axially symmetrical to prevent biasing problems due to changing currents; replicate traps at the same depth should be more than three diameters apart to avoid flow interferences (GARDNER, 1980a).

Fibreglass, conical sediment traps based on the Aberdeen design (PAYNE & DAVIES, 1978) with fins for stability and positive buoyancy built into the neck to keep the trap upright, were the first traps used in this study. The design, its dimensions and a typical deployment array are shown in **Fig. 2.8.1.**

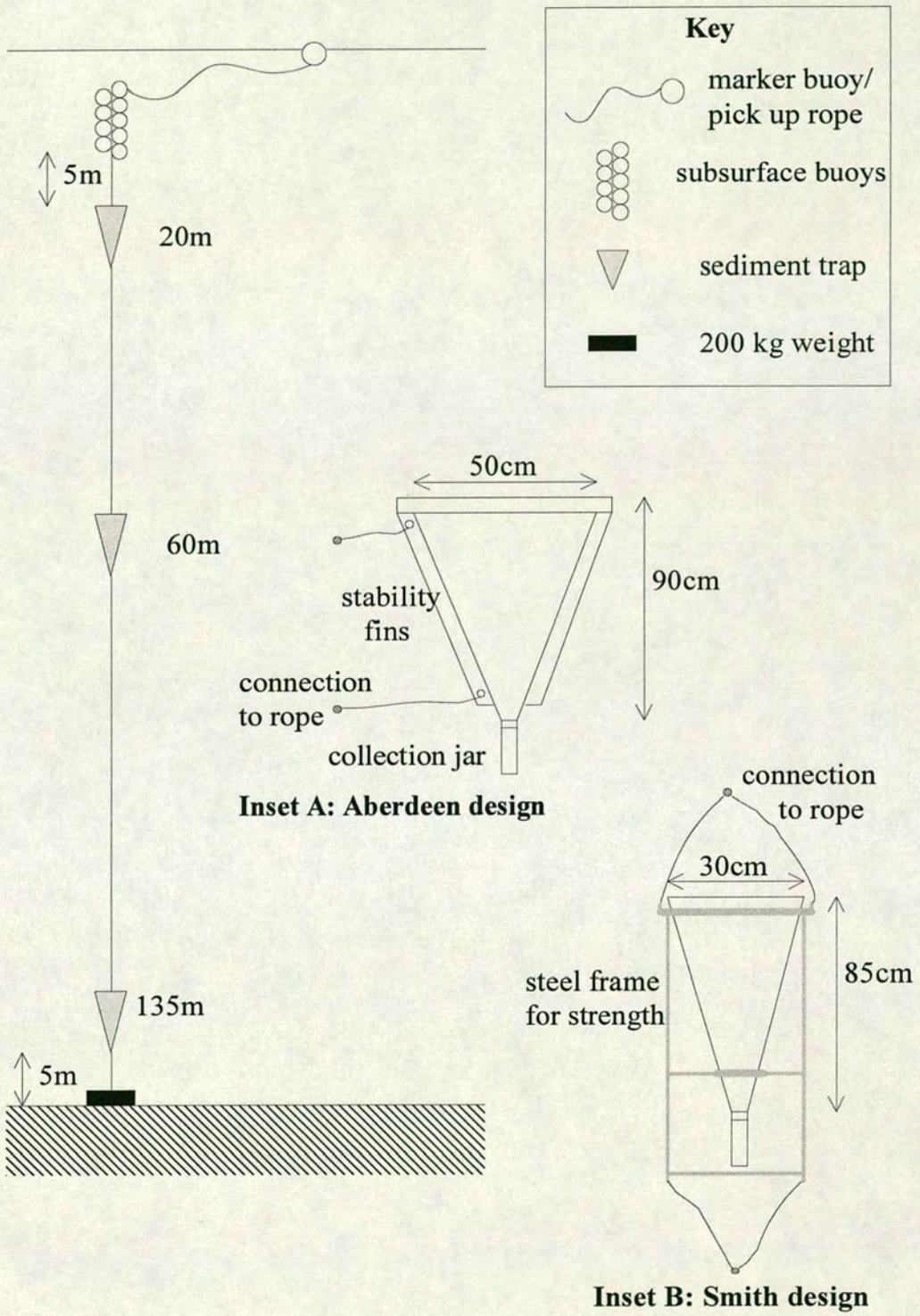


Fig. 2.8.1. Schematic sediment trap array. The rope is held taut between sub-surface buoys and a bottom weight. All connections are provided by shackles and hard eyes. Inset shows two designs of sediment trap. The PAYNE & DAVIES (1978) Aberdeen design is held vertical via in-built buoyancy, the Smith design by insertion into the vertical rope.

The advantages of this design are: the absence of moving parts such as a closing mechanism helps eliminate possible mechanical and electrical malfunction; the all-plastic assembly minimises trace metal contamination; the trap is easy to manufacture; the sample is pre-concentrated into the removable sample bottle allowing easy sample handling and minimisation of sample-wall contact.

The trap is deployed and recovered open, however the amount of material that may be collected or lost during recovery is insignificant (BRULAND *et al.*, 1981). In laboratory experiments GARDNER (1980a) found that conical traps collect at 100 % efficiency in still conditions, while at current speeds of 4 cm s^{-1} the entrapment efficiency was 65 %. Since the current speeds in the deep basin of Loch Etive are negligible except in rare overturn events when mean current speeds can reach ~5 cm s^{-1} (EDWARDS & EDELSTEN, 1977), it is not unreasonable to assume close to 100 % trapping efficiency. BRULAND *et al.* (1981) deployed conical traps in the deep basins of the Southern California Bight and measured vertical particle fluxes in agreement with sediment accumulation rates determined from cores.

A problem of sediment traps in general and the cone design in particular is the tendency of reducing conditions to form in the sample bottle, leading to bacterial degradation of organic matter, with loss of total weight, and organic C, N and P, and remobilisation and loss of Mn. DYMOND *et al.* (1981) found in a trap inter-comparison study that a cone trap had 37 % less Mn than the other designs. BLOESCH & BURNS (1980) estimated that 10 % of organic material may be lost bi-weekly. GARDNER *et al.* (1985) observed a daily loss of 0.1-1 % organic carbon. It is possible to prevent organic degradation by adding poisons such as $HgCl_2$ and NaN_3 or preservatives such as formalin or salt, but these may cause more problems than they solve (LEE *et al.*, 1988: HEDGES *et al.*, 1993). The presence of biological poisons may kill zooplankton which swim into the traps, as opposed to zooplankton that die above the traps and fall into them, thus altering the quantity and composition of the collected material. HEDGES *et al.* (1993) removed huge numbers of swimmers >850 µm from treated traps, but found lowered C/N ratios and higher C_{org} % contents in the bulk sediment suggesting the presence of smaller swimmers not separated by sieving. For this study therefore it was decided not to poison the traps. Short redeployment times are thus ideal, however the monthly servicing employed in this study was considered sufficient.

The traps were first suspended at three depths: 30 m, 85 m, and 145 m which was 5 m off the bottom. In February 1991 the traps broke free from their mooring and were lost (see Appendix **A2.1.** for details) and there was a sampling hiatus while three new traps, of slightly different design were prepared. These were smaller, negatively buoyant and had a metal frame for strength. They were placed between lengths of mooring rope, rather than attached to it, and held vertical by the tautness of the rope. They were deployed at 5 m, 60 m and 135 m (5 m off bottom) as before, however the placement of the topmost trap at 5 m proved to be too shallow, as it was within the photic zone rather than just below it.

In two summer months the collection was swamped by zooplankton and mussels respectively, while in a third the ropes became tangled, the trap overturned and the sample was lost. Consequently the trap was redeployed at 20 m. In December 1991 the surface marker buoy and pick up rope were lost or stolen, and although a trawl of the basin retrieved the upper two traps, and subsurface buoys, the bottom trap was lost. It is possible that the samples which were retrieved from these traps may have been contaminated as the metal frames were found to be rusting badly, and lumps of Fe oxides may have been dislodged during retrieval (see **5.2.**). After another hiatus, and for the remainder of the study, only two traps were deployed at 60 m and 135 m. The sediment traps were suspended a short distance to the south-west of the deep station mooring (N 56 27 27; W 05 11 58). **Table 2.8.1.** summarises the sediment trap deployment details.

Table 2.8.1. Sediment trap deployment details for Loch Etive deep station 1990-1992.

sample code	dates deployed	no. days	deployment depths (m)	comments
ST 1	21.11.90 to 20.12.90	30	30, 85, 145	first design
	20.12.90 to ?		30, 85, 145	traps and samples lost
ST 2	18.4.91 to 22.5.91	33	5, 60, 135	second design
ST 3	22.5.91 to 18.6.91	27	5, 60, 135	top trap swamped with zooplankton
ST 4	18.6.91 to 17.7.91	29	5, 60, 135	top trap turned over on recovery
ST 5	17.7.91 to 12.9.91	57	5, 60, 135	top trap swamped with mussels
ST 6	12.9.91 to 14.10.91	32	5, 60, 135	
ST 7	14.10.91 to 14.11.91	31	20, 60, 135	
ST 8	14.11.91 to 12.12.91	33	20, 60, 135	bottom trap and sample lost
ST 9	17.1.92 to 24.2.92	38	60, 135	
ST 10	24.2.92 to 23.4.92	59	60, 135	
ST 11	23.4.92 to 28.5.92	35	60, 135	
ST 12	28.5.92 to 22.6.92	25	60, 135	

2.9. Sediment

In extremely porous sediments disturbance or loss of surface sediment during coring is a problem (BAXTER *et al.*, 1981). Long (50-60 cm, 8 cm diameter) cores were therefore collected from the deep station (May and Nov. 1991) and Aird's Bay (Nov. 1991) using a slow-entry gravity corer (PEDERSEN *et al.*, 1985), which retains the surface-water interface.

There is a valve at the top of the corer to allow water flow-through, which eliminates pressure waves at the corer mouth. When penetration is complete, the release of tension on the cable closes the valve and the core can be retrieved with suction holding it in place. In practice, in relatively calm conditions, cores are regularly retrieved with clear supernatant water and apparently undisturbed interfaces, with the presence of fine scale features at the surface including a layer of flocculant. There appears to be little mixing down the sides of the core, as the large diameter barrel minimises friction. There was visual inspection of each core taken to check the quality of the interface.

In March 1992 short (7-13 cm, 3 cm diameter) Craib cores (CRAIB, 1965), were taken. This slow-entry hydraulically dampened device is specifically designed to collect only short cores, while retaining the sediment-water interface and floc layer.

In January 1993 a sediment core (10 cm diameter, 65 cm long) was collected using a slow-gravity corer as above, except that the conditions were not very calm, and there was some disturbance of the surface sediment. This core was used to obtain pore water by centrifugation. A summary of the cores taken and the parameters determined on them is shown in **Table 2.9.1.**

Table 2.9.1. Sediment cores taken in this study and parameters obtained on them.

Core	Site	Date	Length of core	Gamma counted	Alpha ^{210}Pb	XRF	C/N	Pore Waters
A	Deep Station	22/5/91	48cm	yes	yes	yes	yes	
B	Aird's Bay	13/11/91	52cm	yes	yes	yes	yes	
C	Deep Station	13/11/91	50cm	0-2cm	yes	yes	yes	
F	Deep Station	19/1/93	60cm					0-60cm
Z	Transect cores	23-26/3/92	7-13cm		yes	yes	yes	

Chapter Three: Hydrography and nutrients during the study period

3.1. Rainfall and freshwater run-off

The rainfall data for several sites in the Etive catchment, weekly where possible, but monthly for some sites, was obtained to investigate the influence of varying rainfall on the hydrographic conditions of Loch Etive, and to enable the calculation of the ^{210}Pb and ^{210}Po rainfall fluxes. Data was supplied by the Meteorological Office, except for the 1992 figures for Dalness Forest in Glen Etive which were provided by Mr A. Hunter. The monthly rainfall results are tabulated in Appendix **B6.3.** The Southern Hydro Group of Scottish Hydro-Electric plc, supplied weekly run-off into Loch Awe, and weekly discharge into Loch Etive results. From these the total freshwater input to Loch Etive has been estimated using **Eqn. 2.2.1.** and these figures are tabulated in Appendix **B6.4.** with the weekly rainfall.

The weekly rainfall recorded at Black Mount is shown in **Fig. 3.1.1.** The other stations show identical patterns, though the quantity of rain increases with proximity to mountains. The weekly run-off from the Loch Awe catchment is also plotted in **Fig. 3.1.1.** The run-off follows the rainfall closely, but with a slight delay. The discharge to Loch Etive also follows the rainfall closely, but the storage of water in Loch Awe buffers the variation, smoothing out and delaying it, with a constant minimum volume let through the Awe barrage even when run-off is zero.

The sampling period generally had a rainfall greater than the average 30 year (1941-1970) value. Although 1991 was a dry year in the rest of the country, the Etive catchment rainfall was around 109 % of average. Monthly percentages of average values are shown in Appendix **B6.3.** Only four months had rainfall less than 90 % of average: February May and August '91, and June '92. There is generally high variable rainfall from October to April with occasional periods of no rainfall, and lower variable rainfall from May to September with more frequent periods of low rainfall. There was low or no rainfall for extended periods in: February '91; May '91; August-September '91; February '92; and May-June '92.

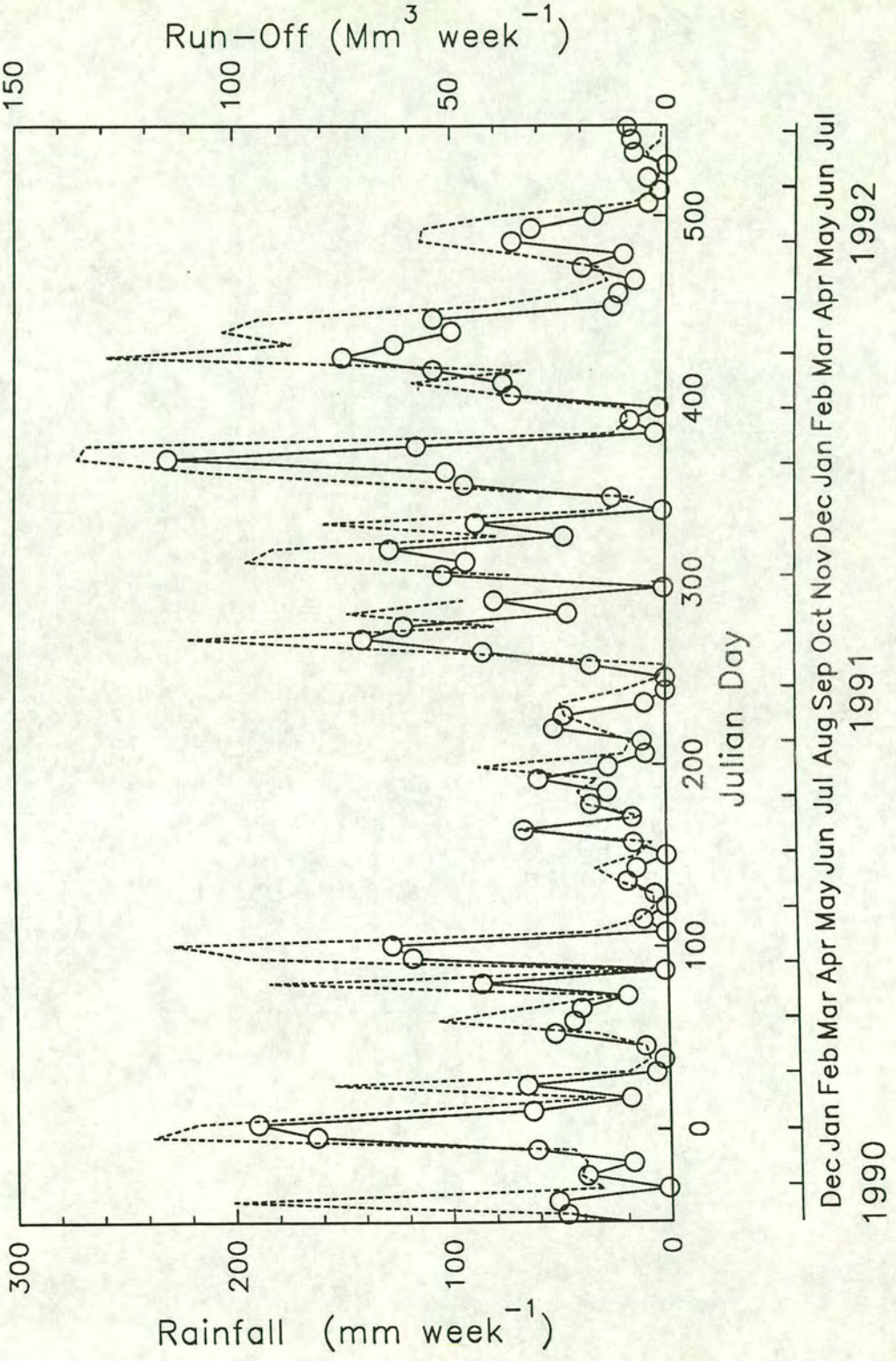


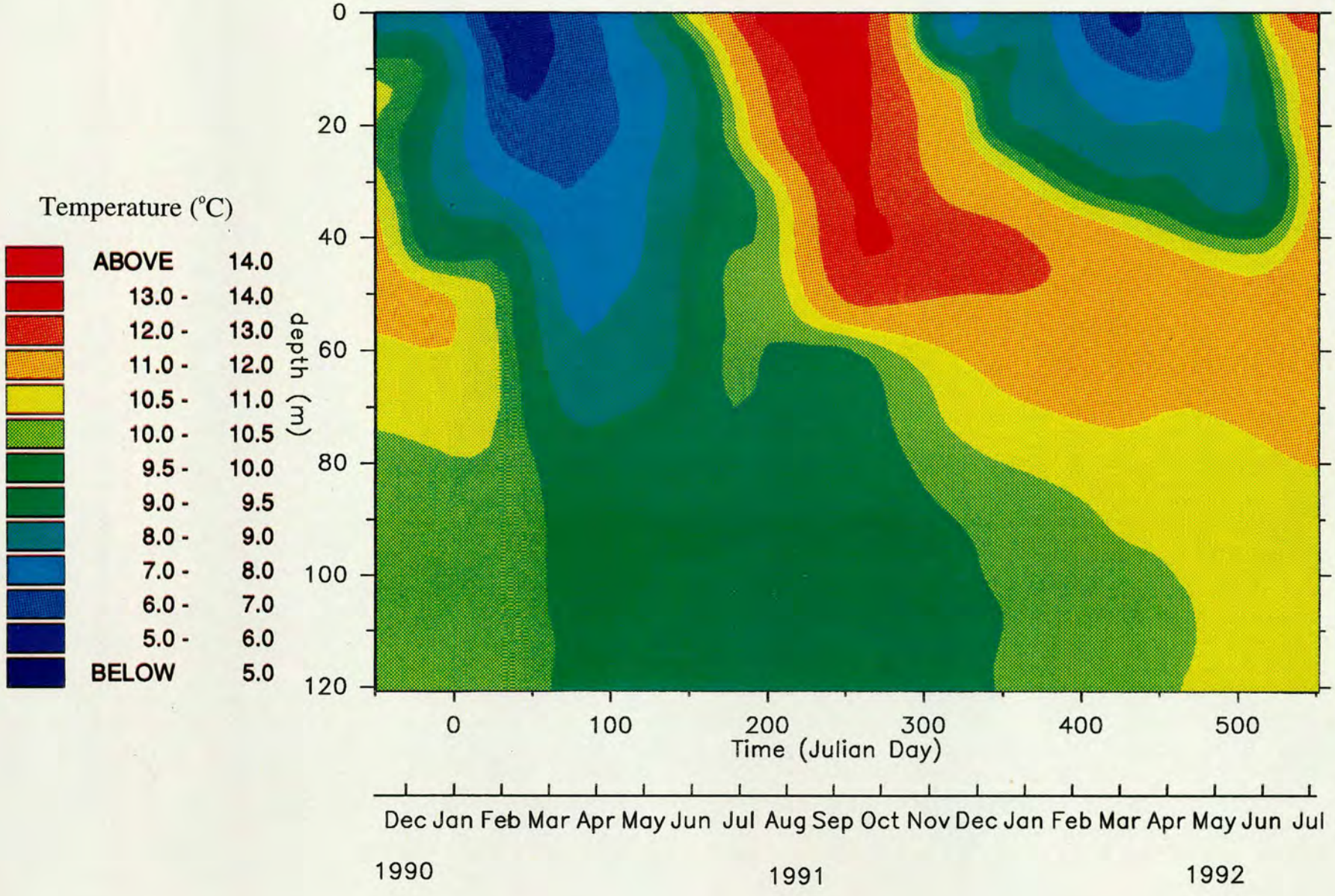
Figure 3.1.1. Weekly rainfall —○—, recorded at Black Mount, in the NE Awe catchment, and run-off - - - - -, from the Awe catchment, both November 1990 - June 1992. Results courtesy of the Meteorological Office, and Scottish Hydro-Electric plc respectively.

3.2. Temperature, salinity and density

The temperature and salinity at the deep station was recorded to enable separations of the various water bodies to be made; to give information on the variation of the water mass with time, especially to determine the presence of overflow occurrences; and to enable the calculation of diffusion constants and fluxes within the water column. The results for 17 months at the deep station and one cast in Aird's Bay are tabulated in Appendix **B6.1.**

The deep station temperature for the study period is contoured in **Fig. 3.2.1.** The changes in the surface temperature are obvious - the minimum temperature recorded was 4.9 °C in February '91 and the maximum 14.4 °C in July '91. The first winter cooling is only evident in the brackish water above 5 m, this is as expected as this water is largely run-off, and the marine water retains its heat. In January and February however the marine-derived water also cools to below 7 °C. The depth this cooling extends to in the intermediate layer is 80 m in the first winter of the study but only 40 m in the second. While this may be partly due to more severe storm events in '91 mixing the water column more than in '92, it is unlikely as the salinity stratification remains in place throughout. It is more likely that partial renewal of summer water by winter sill water extended to different depths each year. This erosive renewal is well illustrated by the temperature depth profiles for November and December '90 (**Fig. 3.3.2.**). Between the two months only the water lying between 20 and 50 m has been replaced. By March '91 the entire water column down to 80 m has been replaced. In the second winter the gradual cooling may have been the result of diffusive transport across the thermocline or storm mixing or more limited erosive renewal. In the summer the reverse process takes place: first the surface layer and then the intermediate layer re-warm. The warming of the intermediate layer takes place over a quicker timescale than the cooling as the warmer weather is associated with lower rainfall (especially May '91 and '92), and erosive renewal more likely in the summer. By September '91 (**Fig. 3.2.2.**) the water column to a depth of 60 m has been warmed.

Figure 3.2.1. (opposite) Temperature at the Deep Station in Loch Etive November 1990 - June 1992. The divisions of the scale are every 1 °C at the extremes of the temperature range and every 0.5 °C in the centre of the range to allow the more subtle variations at the bottom of the deep basin to become apparent.


Temperature (°C)
ABOVE 14.0
13.0 - 14.0
12.0 - 13.0
11.0 - 12.0
10.5 - 11.0
10.0 - 10.5
9.5 - 10.0
9.0 - 9.5
8.0 - 9.0
7.0 - 8.0
6.0 - 7.0
5.0 - 6.0
BELOW 5.0
depth (m)
0
20
40
60
80
100
120
0
100
200
300
400
500
Time (Julian Day)
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
1990
1991
1992

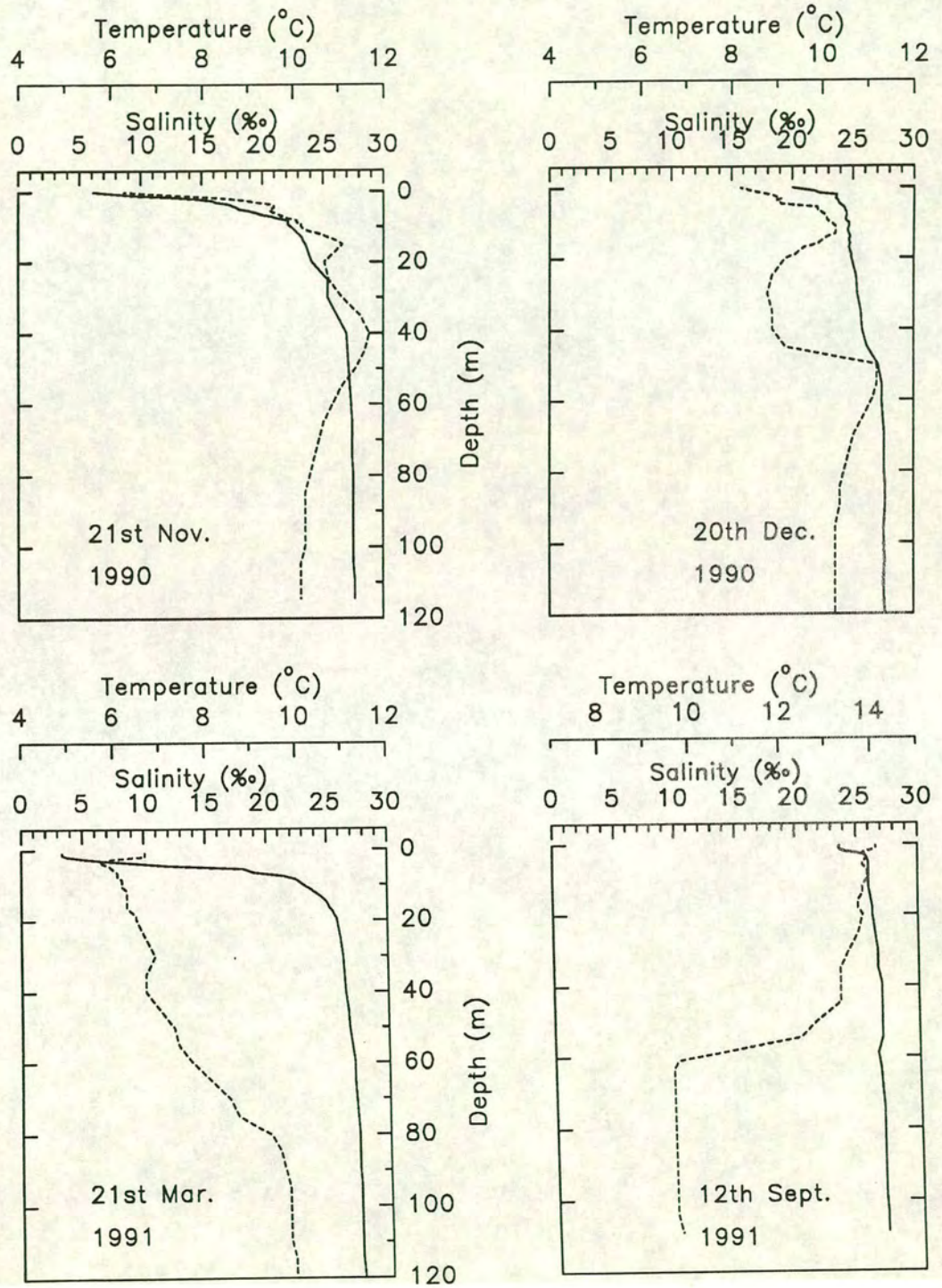
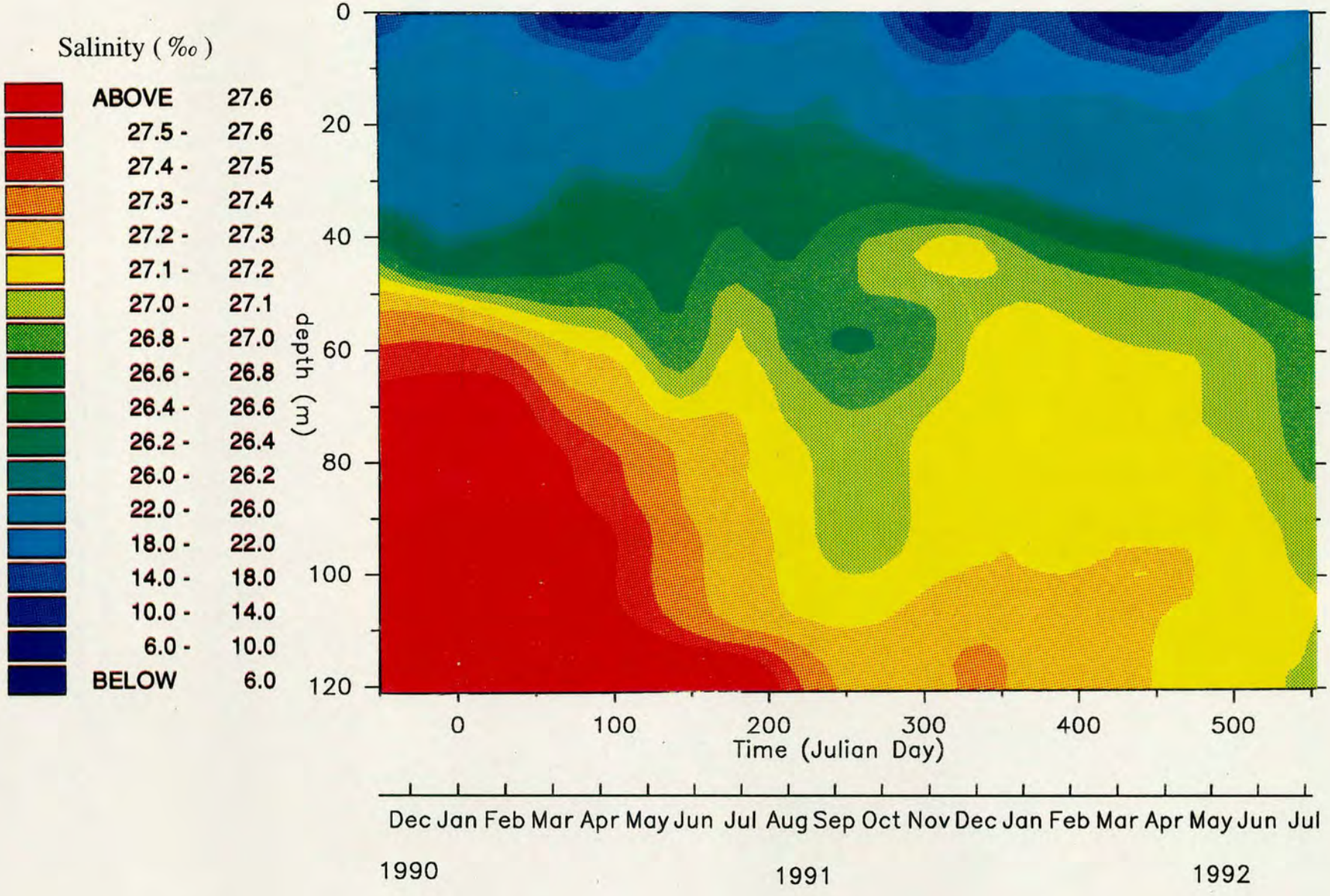


Figure 3.2.2. Examples of temperature - - - - -, and salinity ———, depth profiles at the Deep Station in Loch Etive from November 21st and December 20th 1990, and 21st March and 12th September 1991. Note change of temperature scale in September '91.

Figure 3.2.3. (opposite) Salinity at the Deep Station in Loch Etive 1990-1992, contoured with a pseudo logarithmic scale to better show the small changes at the bottom of the deep basin. For salinities below 26.0 ‰ the divisions are every 4 ‰, between 26.0 ‰ to 27.0 ‰ the divisions are every 0.2 ‰ and above 27.0 ‰ the divisions are every 0.1 ‰.


Salinity (‰)
ABOVE 27.6
27.5 - 27.6
27.4 - 27.5
27.3 - 27.4
27.2 - 27.3
27.1 - 27.2
27.0 - 27.1
26.8 - 27.0
26.6 - 26.8
26.4 - 26.6
26.2 - 26.4
26.0 - 26.2
22.0 - 26.0
18.0 - 22.0
14.0 - 18.0
10.0 - 14.0
6.0 - 10.0
BELOW 6.0
depth (m)
0
20
40
60
80
100
120
0
100
200
300
400
500
Time (Julian Day)
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
1990
1991
1992

In contrast the deep water temperature remained constant throughout. There seems to have been no renewal of the deep water during the study. It is possible that a body of water of the same temperature may have renewed the deep water, but this is unlikely as there was no concurrent salinity increase. The deep water temperature did change slowly, of the order of 0.1 °C a month, and this can be attributed to diffusion across the pynocline. During the first winter when the middle water was colder than the deep water, the deep water temperature fell gradually, while in the second winter the middle water was warmer than the deep water and thus the deep water temperature rose gradually.

The deep station salinity is contoured in **Fig. 3.2.3.** As above the surface salinity varies considerably, with the maximum and minimum salinities recorded 23.7 ‰ in September '91 and 1.3 ‰ in March '92. There is salinity stratification throughout the upper water column in all months with an extremely steep salinity gradient in the top 10 m of the water column, from the variable surface value to about 22-24 ‰ at 10 m. The correlation of the surface salinity with run-off was investigated by integrating the salinity over the top 2 m, 5 m and 10 m, and correlating these monthly values with a monthly integrated run-off figure. This was calculated by summing varying proportions of raw run-off data (from Appendix **B6.4.**) for the weeks prior to sampling. For example when sampling was carried out on the 21st of November '90, week 0 is the 17th to 23rd, week -1 is the 10th to the 16th, and so on. Eighteen different monthly run-off totals were correlated with the three monthly integrated salinity figures as shown in **Table 3.2.1.**

Surface layer salinity and run-off are inversely proportional. The best correlation is between salinity integrated over 0-10 m with run-off total 16 (r^2 = -0.957). This correlation is plotted in **Fig. 3.2.4.** Integrated salinity over 0-2 m, showed the best correlation with run-off total 5 (r^2 = -0.889). Replacement of the extreme surface layer (0-2 m) is thus in the order of days, while the surface layer as a whole (0-10 m) is replaced in three weeks.

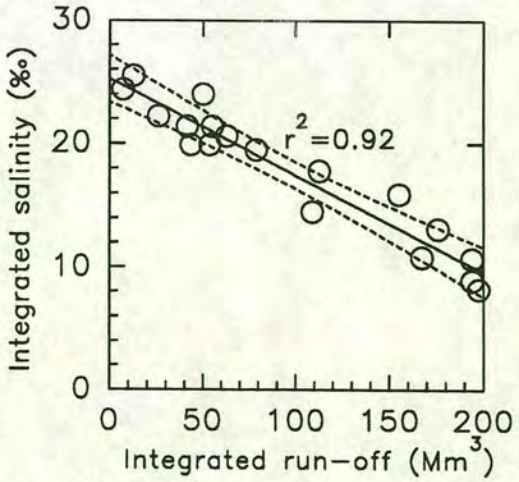


Figure 3.2.4. Correlation of integrated surface salinity (0-10 m) with total run-off (see text for explanation of how this was calculated).

Table 3.2.1. Surface salinity versus run-off correlations.

Code	proportion of each week used in run-off total				correlation of surface salinity with run-off		
	wk 0	wk -1	wk -2	wk -3	**0-2 m**	**0-5 m**	**0-10 m**
1	1				-0.543	-0.575	-0.581
2		1			-0.808	-0.808	-0.813
3			1		-0.454	-0.531	-0.621
4				1	-0.374	-0.433	-0.477
5	1	1			-0.889	-0.910	-0.917
6	1	1	1		-0.853	-0.901	-0.943
7	1	1	1	1	-0.817	-0.876	-0.924
8			1	1	-0.524	-0.610	-0.694
9		1	1		-0.733	-0.774	-0.823
10		1	0.5		-0.659	-0.714	-0.779
11		1	1	1	-0.736	-0.792	-0.849
12		1	0.5	0.25	-0.792	-0.825	-0.863
13	0.5	1	0.5	0.25	-0.875	-0.915	-0.950
14	0.5	1	0.5		-0.854	-0.904	-0.947
15	0.75	1	0.75	0.5	-0.879	-0.913	-0.944
16	0.75	1	0.5	0.25	-0.883	-0.924	-0.957
17	1	1	0.5	0.25	-0.878	-0.920	-0.951
18	0.75	1	0.25	0.25	-0.885	-0.920	-0.942

EDWARDS & SHARPE (1991) give the flushing time (loch volume/tidal flow rate; time taken for about 60 % of the water originally present to be replaced by tidal exchange) of Loch Etive as 14 days, which is the largest of any Scottish sea loch. Consequently overturns are only possible after long periods of low rainfall. In addition storage of freshwater in Loch Awe further slows the response time to changes in rainfall and EDWARDS & EDELSTEN (1977) suggested that this has the potential to half the frequency of deep water renewal.

The erosive renewals of the intermediate layer discussed above can be explained well by referral to the run-off and salinity data. Unusually low rainfall (e.g. the run-off for the period 26.1.91 - 22.2.91 was 35 Mm^3 in comparison to 262 Mm^3 and 188 Mm^3 for the preceding and following four week periods respectively) resulted in unusually high winter salinity values twice in the first winter (it was recorded in both December '90 and February '91 as 20.0 ‰) and it was presumably dense enough to spill over and replace the water to 45 m on the first occasion and to 80 m on the second. In contrast the surface salinity remained low during the winter of 1991-92, with the run-off and rainfall much higher and presumably erosive renewal did not take place, except perhaps after the period of low run-off in February '92.

The deep water is more intermediate, e.g. there is a change of only 0.2 ‰ from 70 to 120 m in November '90. At the beginning of the study the secondary pynocline is situated between 40 and 60 m and is comparatively strong. As the first winter proceeds it deepens and becomes more diffuse until by late summer of '91 there is only 1.0 ‰ difference between the salinity at 20m and that at 100m. The deep water salinity falls slowly from 27.7 to 26.9 ‰ by about the order of 0.05 ‰ a month, presumably due to diffusion across the pynocline. EDWARDS & GRANTHAM (1986) measured salinities in the deep basin, falling from ~29 ‰ to ~28 ‰, by roughly 0.05 ‰ a month, during a two-year stagnant period from June '80 to June '82. EDWARDS & EDELSTEN (1977) found stagnant bottom water salinities of 27.7- 27.5 ‰ which then increased to 28.3 ‰ due to renewal, in April and May '71. The extremely low bottom salinities found in the course of this study suggests that the bottom water might be very old - "super stagnant". However between September and November '91 there is a small increase in deep salinity from 27.0 to 27.3 ‰ suggesting that there was partial deep renewal. The surface temperature at this time was 14.1 °C and the deep temperature 9.6 °C, so if there was a renewal there should have been a significant deep temperature change. The temperature did rise to 9.9 °C at depth suggesting a partial overspill and subsequent mixing of old and new water to produce the new temperature, but the picture is made complicated by the apparent diffusion across the pynocline increasing the temperature of the top of deep water by a larger amount that the deep increase. Assuming endmembers of 14.1 and 9.6 °C an increase of 0.3 °C suggests that 8 % of the deep water was replaced. This period correlates with low freshwater input - there was no rain in a three week period from 23rd August to 12th September. On the 13th of September however there was a very heavy rainfall, of around 30mm, and this appears to have stopped the ongoing deep renewals suddenly. Similar periods of low rainfall in May '91 and May-June '92 only resulted in erosive renewal to 75 m. Low rainfall continued for several weeks after the last sampling trip on 20th June '92, and it is very possible that the only full deep renewal for two years fell just outside the boundaries of this study.

3.3. Nutrients and oxygen

The dissolved oxygen content of the deep station waters was determined to give information on their redox state and stagnation state, and to allow diffusion and degradation fluxes to be calculated. The dissolved oxygen results obtained by CTD

casts are tabulated in Appendix **B6.1.**, while those determined by titration are tabulated with the dissolved phosphate and silicate results in Appendix **B6.2.** Nitrate was not determined. To remove temperature and salinity effects, the oxygen concentration over the sampling period has been expressed as a percentage of the theoretical saturation value (WEISS, 1970), and is contoured in **Fig. 3.3.1.**

The surface water was super-saturated in oxygen in both late spring periods due to phytoplankton photosynthesis. The bottom water oxygen concentration fell slowly throughout the study period, but was never fully anoxic despite the extended period of stagnation, because the productivity, and hence rate of oxygen utilisation, in Loch Etive is low (WOOD *et al.*, 1973), compared to other lakes and fjords which may become anoxic within a single season after renewal.

During the first winter the deep water dissolved oxygen concentration fell slowly from 3.2 to 3.0 ml l^{-1}. Between May and June '91 there was a small increase in dissolved oxygen concentration, which coincided with an erosive input of oxygenated water to 75 m depth, and presumably diffusion of oxygen to depth. During the second winter the deep oxygen concentration fell more rapidly from 3.4 to 2.4 ml l^{-1}. Since the waters between 40 and 80 m in depth were not renewed in the second winter until May '92, an assumption may be made that diffusion of oxygen to the deep water could not take place to compensate for the oxygen being utilised in organic degradation. A drop in oxygen concentration of 1.0 ml l^{-1} in 6 months is equivalent to an organic utilisation of 5.36 mg l^{-1} $year^{-1}$ or 322 g m^{-2} $year^{-1}$, taking the depth of the stagnant water to be 60 m.

Rates of oxygen consumption and inorganic nutrient regeneration were measured in Loch Etive during a two-year stagnant period by EDWARDS AND GRANTHAM (1986). They used trapped deep basin water as a "natural bell jar" experiment, free from advection, where the diffusive fluxes could be estimated from conservative properties. Immediately after deep renewal in June '80, the dissolved oxygen concentration was ~6 ml l^{-1}, then it fell rapidly to less than 3 ml l^{-1} by February '81. Since there was little vertical difference in the water column, the downwards diffusion was small. As the difference between the middle and bottom waters increased, so did the rate of diffusion, and the rate of oxygen depletion decreased. A partial renewal to 70 m in May '91 slowed the depletion of deep oxygen further, and in the second year of stagnation, the system was almost at steady-state, although the dissolved oxygen did fall to ~2 ml l^{-1} by June '82 when deep renewal took place.

Figure 3.3.1. (opposite) Dissolved oxygen concentration at the Deep Station in Loch Etive 1990-1992, expressed as a fraction of the theoretical saturated value (1.0 represents 100% saturated).

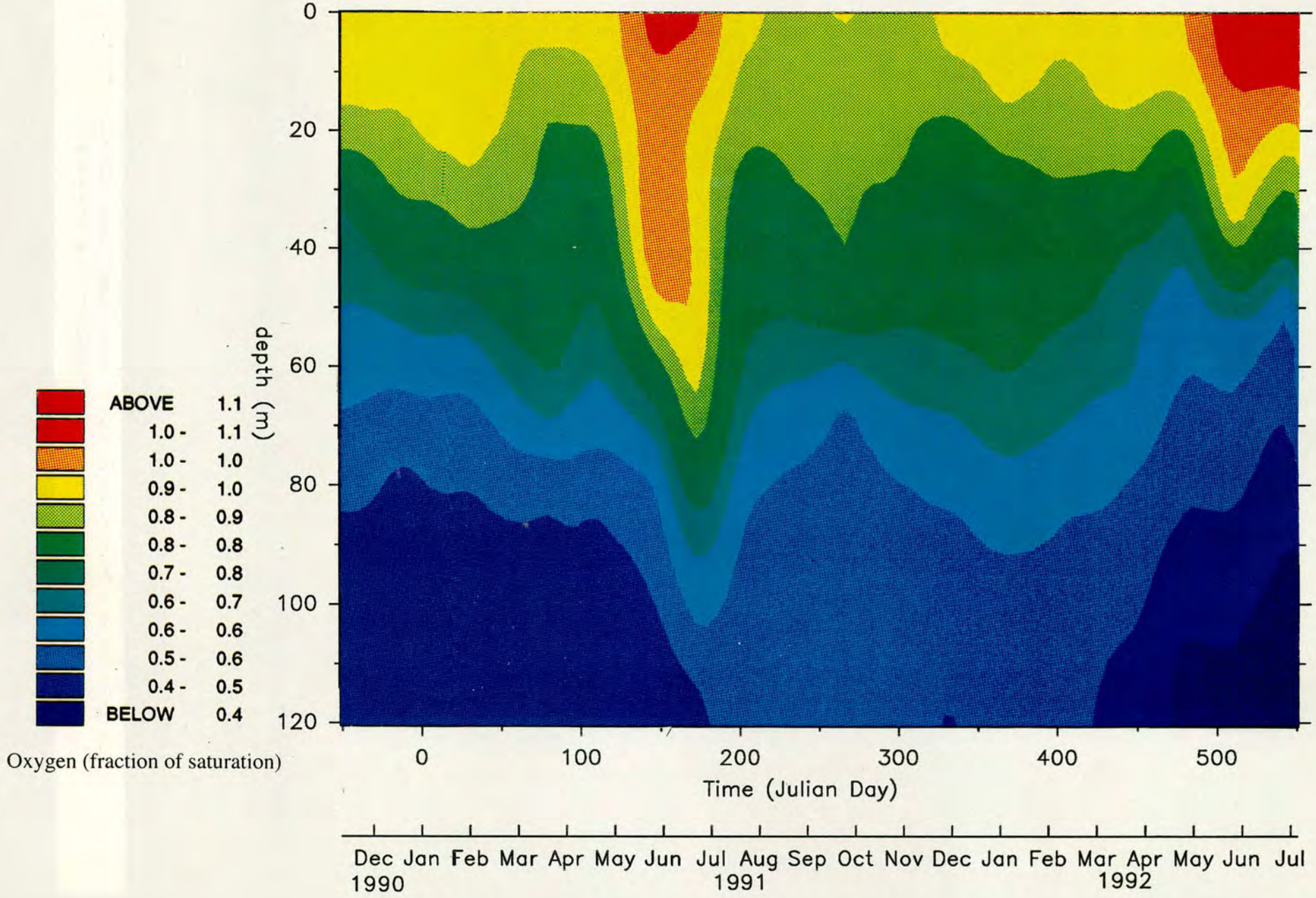
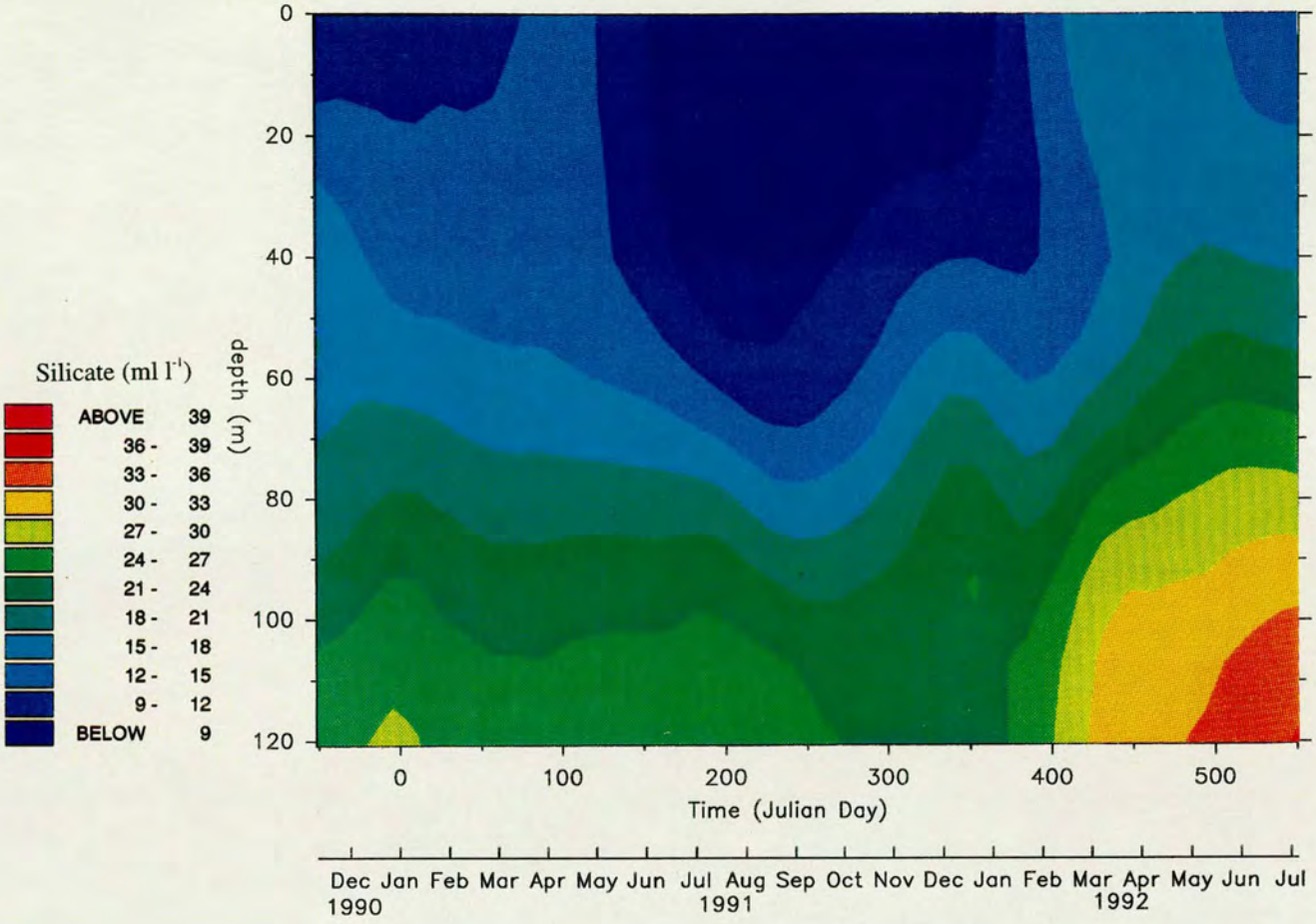
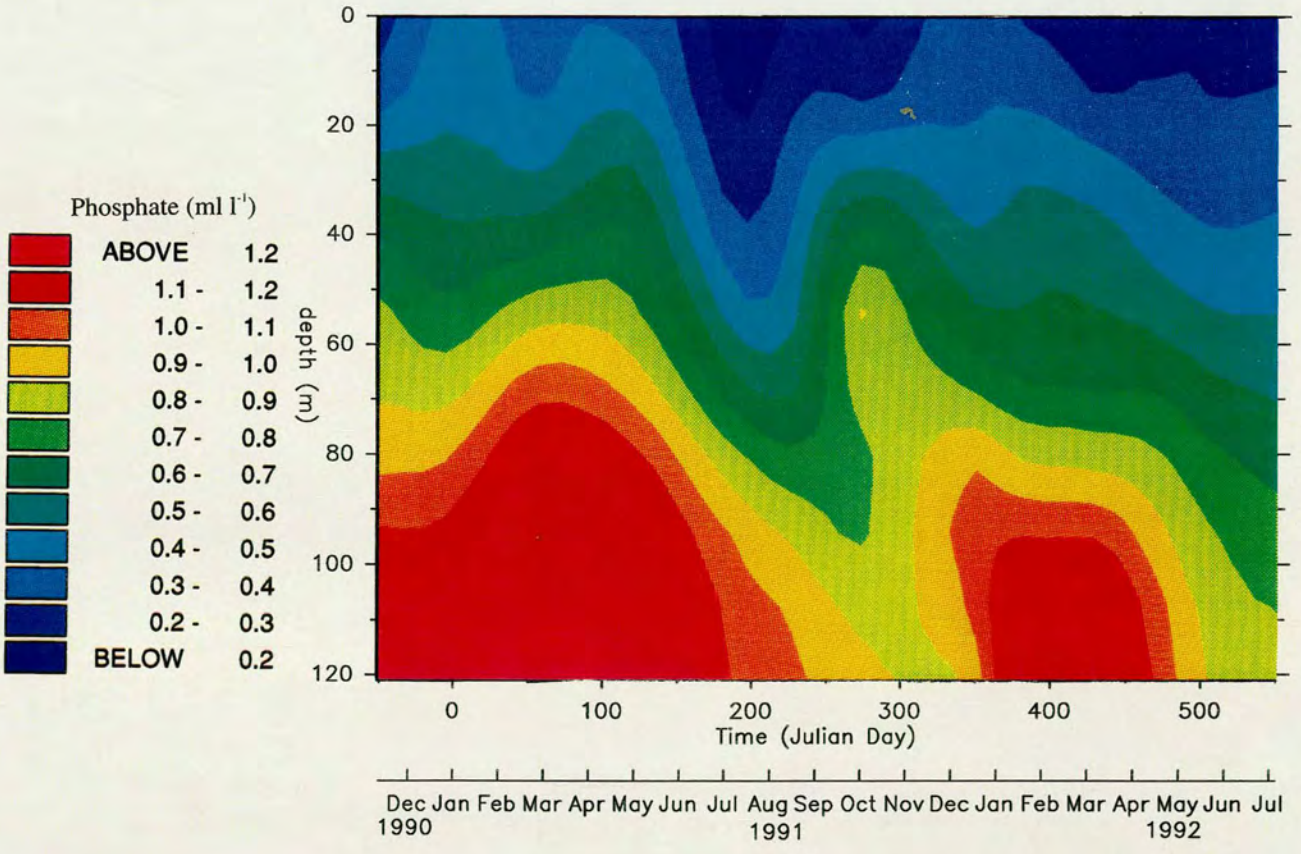

ABOVE 1.1
1.0 - 1.1
1.0 - 1.0
0.9 - 1.0
0.8 - 0.9
0.8 - 0.8
0.7 - 0.8
0.6 - 0.7
0.6 - 0.6
0.5 - 0.6
0.4 - 0.5
BELOW 0.4
Oxygen (fraction of saturation)
depth (m)
0
20
40
60
80
100
120
0
100
200
300
400
500
Time (Julian Day)
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
1990
1991
1992

Figure 3.3.2. (opposite, upper) Dissolved phosphate concentration. **Figure 3.3.3.** (opposite, lower) Dissolved silicate concentration. Both determined at the Deep Station in Loch Etive 1990-1992.


Silicate (ml l-1)
ABOVE 39
36 - 39
33 - 36
30 - 33
27 - 30
24 - 27
21 - 24
18 - 21
15 - 18
12 - 15
9 - 12
BELOW 9
depth (m)
0
20
40
60
80
100
120
0
100
200
300
400
500
Time (Julian Day)
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
1990
1991
1992


Phosphate (ml l-1)
ABOVE 1.2
1.1 - 1.2
1.0 - 1.1
0.9 - 1.0
0.8 - 0.9
0.7 - 0.8
0.6 - 0.7
0.5 - 0.6
0.4 - 0.5
0.3 - 0.4
0.2 - 0.3
BELOW 0.2
depth (m)
0
20
40
60
80
100
120
0
100
200
300
400
500
Time (Julian Day)
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
1990
1991
1992

Similarly the nutrients showed their greatest increase in the first few months of stagnation, and by spring 1981 had reached steady-state. Phosphate rose from <1 to >2 μmol l^{-1} ; nitrate from ~2 to ~12 μmol l^{-1} ; silicate from ~20 to 40-50 μmol l^{-1} . The stoichiometric ratio for the oxygen consumption and nutrient regeneration rates was O:N:Si:P of 320:10:31:1 which is similar to the Redfield ratio, except that the high silicon flux suggests a silicon-rich source in Loch Etive and the low N:P ratio may be a terrestrial influence as low N:P ratios are commonly found in coastal waters (EDWARDS AND GRANTHAM, 1986).

The deep station phosphate and silicate concentrations over the study period are contoured in **Fig. 3.3.2.** and **Fig. 3.3.3** respectively. The surface waters are depleted in nutrients, and this depletion increases during the summer period. The surface phosphate concentration falls from 0.38 μmol l^{-1} over the winter of '90 - '91, to 0.06 μmol l^{-1} in May '91, while that of silicate falls from 12 to 4 μmol l^{-1}. The concentration of the nutrients increases with depth, with typical deep water phosphate concentrations of 1.3 - 1.5 μmol l^{-1}, and silicate concentrations of 28 - 31 μmol l^{-1}. The sample from 110 m on 12.9.91 has lower nutrient concentrations than the months before and after and the 70 and 90 m samples above it. This is attributable to low-nutrient surface water overturning and mixing with high-nutrient deep water. This corresponds with the partial overturn already identified from the low rainfall figures, and salinity, temperature and dissolved oxygen data. For phosphate, taking end members of 0.07 and 1.35, and a intermediate value of 0.67 suggests that 53 % of the deep water was replaced. For silicate, end members of 1.4 and 26.8 and a intermediate value of 20.6, suggests that 26 % of the deep water was replaced. There is thus disagreement between the amount of deep water replacement, estimated by the nutrients and that using the temperature data.

3.4. Summary

The developing hydrology of Loch Etive and its catchment, over the 20-month course of the study is summarised in **Table 3.4.1.** In most months there was a halocline at ~10 m, separating the fresh and marine water. Similarly there was a thermocline, separating older stratified water from newer more mixed water, at ~ 60 m in most months, although it deepened to 70-80 m in the first winter. In September '91 a particle rich layer at 58 m was evident on the research vessel's echo sounder.

This coincides with a very strong thermocline at this depth (**Fig. 3.2.2.**). The inner basin of Loch Etive can therefore be separated into three layers. The surface layer (0-10 m) is highly dynamic and the highly variable temperature and salinity are controlled by environmental conditions. The intermediate layer (10-60 m) is stratified, but water renewal is common, so that the temperature warms in summer and cools in winter. The deep layer (60-120 m) is stratified, and water renewal is uncommon, so that the temperature is constant for months at a time, while the salinity slowly falls, by 0.05 ‰ a month due to diffusion.

Table 3.4.1. Summary of monthly hydrological features 1990-1992.

Nov. '90	Moderately high rainfall for most of month, no overspills, low-salinity cap present on sampling.
Dec. '90	Low rainfall in the second week in December resulted in an overspill eroding waters between 20 and 45 m (temperature change from 11 to 9 °C), and a high surface salinity when sampling took place.
Jan. '91	Rainfall is high for most of winter. Diffusion smoothes out the temperature profile at 45-65 m, storm-mixing removes the remnant high temperature water at 5-25 m.
Feb. & Mar. '91	The rainfall was high for most of the period, resulting in low salinity when both sampling trips took place. However low rainfall in late February, caused overspill and erosion of the water from 40-80 m.
Apr. '91	Initial high rainfall had ceased by the time sampling took place, so that surface salinity was creeping up (7 ‰). There was no further erosion, only diffusive mixing smoothing out the temperature profile.
May. '91	Surface waters supersaturated in oxygen, due to spring bloom photosynthesis. Low rainfall continued to the second week, allowing overspill to replace cold water to 70 m with warmer water. Surface salinity was high when sampling took place. Summer warming in the top 5 m. A further overspill took place at the end of month replacing water from 45-80 m with warmer water.
Jun. '91	High rainfall all month. Surface waters supersaturated in oxygen.
Jul. '91	High rainfall all month. Top 5 m has warmed to 14 °C, 5-25 m to 12 °C.
Aug. '91	High rainfall for first two weeks, then no rainfall for the rest of the month.
Sep. '91	For the first two weeks there was no rainfall, and only the compensation flow passed through the Awe barrage. By the 12th of September, the top 60m had been completely replaced by warm water (14 °C), but the deep water was still 9.9 °C. The surface salinity was very high (25 ‰). By the following sampling trip the deep water temperature had risen to 10.2 °C, indicating limited overspill to the bottom. There was increase in the oxygen content of the deep water and decrease in the nutrient content. On the 13th there was very heavy rainfall, stopping deep renewal.
Oct. '91	High rainfall, mixing smoothed out the sharp 60 m thermocline to a gradual 45-100 m change.
Nov. '91 to Apr. '92	High rainfall all winter. Surface salinity was low when sampling took place on 13th Nov., 24th Feb., 24th Mar., and 23rd Apr. (surface salinity was high on 12th of Dec as the first week in December had low rainfall). There was no erosion below 45 m for the whole winter and no erosion at all from Dec. '91 to Mar. '92. There was replacement of warm water between 20-40 m with cold water around the first week of Dec. and in the first week in Apr. there was erosion to 40m.
May. & Jun. '92	The surface water was supersaturated in oxygen and depleted in nutrients throughout. There was erosion to 30 m in May, with surface warming, then erosion of water from 5 to 70 m, at some point before the 20th of Jun.

Chapter 4: Radionuclide distributions in Loch Etive water column.

4.1. Introduction

Since the concentrations of natural radionuclides in aquatic samples are low it is necessary to pre-concentrate the radionuclides present in large volumes of sample by some method. Large volume (10-25 l) water samples were filtered through 0.45 μm membrane filters and the radionuclides present in the filtrate co-precipitated with a Co-APDC complex which was also retained by filtration. The method is described in detail in Appendix **A1.3.** The Stand-Alone Pump (SAP) filters large volumes (80-200 l, depending on time of deployment and particulate loading) of water *in-situ* through 0.45 μm membrane filters, and through wound polypropelene cartridges, these having a large surface area, impregnated with MnO_2 to retain dissolved radionuclides. To collect sufficient volumes of rainwater for $^{210}Pb/^{210}Po$ analysis it was decided to collect rainfall from a large area, thus the run-off from an aluminium greenhouse roof was collected into a carboy previously washed with sample. It was assumed that there would be no ^{210}Po or ^{210}Pb contamination of the rainwater from the aluminium. Large volumes (25-30 l) were collected in short time periods (overnight) in this way.

Analysis for ^{210}Pb and ^{210}Po was via the method of FLEER & BACON (1984), which is described in detail in Appendix **A1.3.** After complete dissolution of particulate and dissolved samples in hot concentrated acids, the ^{210}Po activity was determined by alpha spectroscopy. The samples were stored for six to eighteen months to allow radioactive decay of ^{210}Pb to ^{210}Po, and the ^{210}Po activity was redetermined and assumed to be equivalent to the ^{210}Pb activity in the sample. Errors, typically 10 %, are mainly from propagation of 1σ counting errors. The results of the radioactive analysis will be given in Bq m^{-3} and Bq kg^{-1} which are the S.I. units recommended by IAPSO (1985).

4.2. $^{210}Pb/^{210}Po$ in rain and river samples

River water samples were collected from the river Awe 100 m below the Awe barrage, and from the river Etive 1 km upstream from Dalness (see **Fig 2.1.1.**). These points were chosen for convenience of sampling, and it was assumed that the composition of the water at these points was representative of the water entering Loch Etive. There is wide variation in the ^{210}Pb and ^{210}Po river water specific activity, tabulated in **Table 4.2.1.**, but this variation was within that found by other researchers, whose results are tabulated in **Table 4.2.2.**

Table 4.2.1. Particulate, dissolved and total ^{210}Pb and ^{210}Po activities, dissolved/particulate ^{210}Pb and ^{210}Po ratios and $^{210}Po/^{210}Pb$ ratio in Rivers Awe and Etive water.

River	date sampled	**particulate ^{210}Pb** ($Bq\ m^{-3}$)	**dissolved ^{210}Pb** ($Bq\ m^{-3}$)	**total ^{210}Pb** ($Bq\ m^{-3}$)	**diss./partic. ^{210}Pb ratio**
Awe	14/10/91	0.311 ± 0.029	0.505 ± 0.042	0.817 ± 0.051	1.6 ± 0.20
Etive	14/10/91	0.233 ± 0.023	0.936 ± 0.080	1.169 ± 0.084	4.0 ± 0.52
Etive	12/12/91	0.979 ± 0.094	2.708 ± 0.210	3.687 ± 0.230	2.8 ± 0.34
Awe	23/4/92	-	-	1.027 ± 0.073	-
Etive	28/5/92	-	-	0.468 ± 0.036	-
Etive	20/6/92	0.214 ± 0.026	0.404 ± 0.041	0.618 ± 0.048	1.9 ± 0.30
Mean		**0.43 ± 0.33**	**1.14 ± 0.93**	**1.30 ± 1.09**	**2.6 ± 3.0**
River	date sampled	**particulate ^{210}Po** ($Bq\ m^{-3}$)	**dissolved ^{210}Po** ($Bq\ m^{-3}$)	**total ^{210}Po** ($Bq\ m^{-3}$)	**diss./partic. ^{210}Po ratio**
Awe	14/10/91	0.829 ± 0.051	2.681 ± 0.076	3.511 ± 0.092	3.2 ± 0.219
Etive	14/10/91	1.816 ± 0.105	0.385 ± 0.018	2.201 ± 0.106	0.21 ± 0.016
Etive	12/12/91	3.958 ± 0.222	6.499 ± 0.174	10.456 ± 0.282	1.6 ± 0.102
Awe	23/4/92	-	-	4.955 ± 0.193	-
Etive	28/5/92	-	-	2.834 ± 0.171	-
Etive	20/6/92	0.463 ± 0.038	0.834 ± 0.053	1.297 ± 0.065	1.8 ± 0.187
Mean		**1.77 ± 1.39**	**2.60 ± 2.32**	**4.21 ± 3.01**	**1.5 ± 1.7**
River	date sampled	**particulate $^{210}Po/^{210}Pb$ ratio**	**dissolved $^{210}Po/^{210}Pb$ ratio**	**total $^{210}Po/^{210}Pb$ ratio**	
Awe	14/10/91	2.67 ± 0.30	5.31 ± 0.47	4.30 ± 0.29	
Etive	14/10/91	7.79 ± 0.89	0.41 ± 0.04	1.88 ± 0.16	
Etive	12/12/91	4.04 ± 0.45	2.40 ± 0.20	2.84 ± 0.19	
Awe	23/4/92	-	-	4.82 ± 0.39	
Etive	28/5/92	-	-	6.06 ± 0.59	
Etive	20/6/92	2.16 ± 0.32	2.06 ± 0.25	2.10 ± 0.19	
Mean		**4.17 ± 2.55**	**2.55 ± 2.04**	**3.67 ± 1.66**	

Table 4.2.2. Comparison with literature stream and river ^{210}Pb and ^{210}Po concentrations. Entries in form: mean; standard deviation; range; number of samples.

Location	**partic. ^{210}Pb** ($Bq\ m^{-3}$)	**diss. ^{210}Pb** ($Bq\ m^{-3}$)	**total ^{210}Pb** ($Bq\ m^{-3}$)	**Reference**
Rivers Etive & Awe	0.43 ± 0.33 (0.23-0.98, n=4)	1.14 ± 0.93 (0.40-2.71, n=4)	1.30 ± 1.09 (0.47-3.69, n=6)	This study
Ma. streams E. USA	0.41 ± 0.43 (0.10-2.12, n=23)	1.57 ± 0.53 (0.28-2.92, n=23)	1.98 ± 0.74 (0.48-3.73, n=23)	BENOIT & HEMOND, 1987
Pa. streams N.E. USA	–	–	0.18 ± 0.14 (0.17-0.38, n=4)	LEWIS, 1977
Susquehanna River, USA	3.33 ± 2.00 (1.00-7.00, n=5)	0.17 ± 0.13 (0.05-0.42, n=6)	3.53 ± 2.02 (1.08-7.17, n=5)	LEWIS, 1977
alpine Rhône Switzerland	2.16 ± 2.07 (0.78-7.10, n=52)	0.44 (0.07-1.33, n=25)	2.61 ± 2.21 (1.07-7.55, n=25)	DOMINIK *et al.*, 1987
Connecticut River, USA	–	–	4.20 ± 4.64 (1.80-13.6, n=6)	BENNINGER, 1978
Location	**partic. ^{210}Po** ($Bq\ m^{-3}$)	**diss. ^{210}Po** ($Bq\ m^{-3}$)	**total ^{210}Po** ($Bq\ m^{-3}$)	**Reference**
Rivers Etive & Awe	1.77 ± 1.39 (0.46-3.96, n=4)	2.60 ± 2.32 (0.38-6.50, n=4)	4.21 ± 3.01 (1.30-10.46, n=6)	This study
Ma. streams E. USA	0.40 ± 0.34 (0.13-1.78, n=23)	1.86 ± 0.55 (0.75-2.88, n=23)	2.24 ± 0.72 (0.95-4.03, n=23)	BENOIT & HEMOND, 1987

Few conclusions can be drawn from the limited sample set. Most radioactivity was found in the dissolved fraction, with the dissolved/particulate ratio averaging 2.6 ± 3.0 for ^{210}Pb and 1.5 ± 1.7 for ^{210}Po. The other "streams" show similar ratios, while the "rivers" contain more particulate ^{210}Po and ^{210}Pb than dissolved. There are a number of possibilities which could explain this distribution. Firstly the different flow conditions of streams and rivers may cause the difference; perhaps the rivers contain more particulate material which could scavenge ^{210}Pb and ^{210}Po. However faster-flowing streams would be expected to carry more particulate material than slower rivers, which is the opposite to the observed effect. Secondly the observed effect may be due to differing chemistries between the two sets of rivers. SCOTT (1982) suggests that ^{210}Pb will be almost entirely associated with the particulate fraction in rivers due to its strong particle reactivity. He suggests that only acid rivers will have appreciable dissolved ^{210}Pb. The streams sampled by BENOIT & HEMOND (1987) are slightly acidic, while the streams sampled in this study drain peaty terrain and so are presumably acidic. Finally the radioactivity in the <0.45 μm phase may actually be associated with colloids and not strictly dissolved. This colloidal ^{210}Pb

and ^{210}Po may be affected by the different chemistries or flow conditions in some unknown manner. The dissolved/particulate ratio is greater for ^{210}Pb than for ^{210}Po, presumably because ^{210}Po is more particle reactive than ^{210}Pb.

There was more ^{210}Po than ^{210}Pb in all but one sample, and the ^{210}Po/^{210}Pb ratio averaged 4.17 ± 2.55 in the particulate samples and 2.55 ± 2.04 in the dissolved samples. There was no obvious seasonal variation in nuclide activity, ^{210}Po/^{210}Pb ratio or particulate/dissolved ratio. There was no apparent correlation with changing flow conditions. In monthly sampling of Massachusetts streams in eastern USA, BENOIT & HEMOND (1987) also found no significant correlation with changing flow conditions or season. The ^{210}Pb activities found are similar to those found by BENOIT & HEMOND (1987), while the ^{210}Po activities found are a factor of 2 greater.

The samples taken on 12.12.91 have very large ^{210}Pb and ^{210}Po activities, and it may be possible that this was caused by a rain storm, that was not large enough to dilute the radionuclides, washing out radionuclides that had built up after an extended dry period. There is only a weekly rainfall record, but it is consistent with this scenario. There was only 1.4 mm of rain in the week of 31.11.91 to 6.12.91 and then there was 24.8 mm in the following week of 7.12.91 to 13.12.91. None of the other river sampling dates had dry spells prior to them. There are not enough samples to attempt a correlation.

The River Awe contains waters which have passed through the low-energy environment of Loch Awe, where a fraction of the total radioactivity would be expected to fall out of suspension. However there were no apparent differences between the ^{210}Pb and ^{210}Po activities or the ^{210}Pb/^{210}Pb ratio of the two rivers.

Rainwater

Rainwater was collected monthly at Kilmore (see **Fig. 2.1.1.**) by exposing a collection vessel for 12 to 24 hours. The disadvantage of this is that unrepresentative samples may have been collected. An alternative method of collection would have been to deploy a vessel permanently to collect all the rain deposited over the month. However it is not possible to decay-correct for short-lived ^{210}Po in such a study. Consequently ^{210}Po is rarely determined in rainfall, and thus the mechanisms controlling its distribution in rainfall are poorly understood.

Table 4.2.3. Total ^{210}Pb and ^{210}Pb activities in Kilmore rain water.

Date of sampling	**^{210}Pb** (Bq m^{-3})	**^{210}Po** (Bq m^{-3})	**$^{210}Po/^{210}Pb$ ratio**
18/2/92	47.8 ± 3.7	53.5 ± 1.9	1.12 ± 0.10
23/2/92	26.7 ± 2.3	26.4 ± 1.0	0.99 ± 0.09
23/3/92	64.8 ± 6.5	24.6 ± 1.2	0.38 ± 0.04
22/4/92	61.0 ± 4.9	49.2 ± 2.2	0.81 ± 0.07
22/5/92	74.3 ± 6.1	330 ± 18	4.44 ± 0.44
13/6/92	48.3 ± 4.2	101 ± 5.3	2.09 ± 0.21
Mean	**53.8 ± 15.0**	**97.5 ± 107**	**1.64 ± 1.49**

There is a seasonal variation in the $^{210}Po/^{210}Pb$ activity ratio of the rainfall (see **Table 4.2.3.**). In February the ratio is close to unity, in March and April it is much less than one, while in May and June it is much greater than one. TUREKIAN, *et al.* (1977) noted that the $^{210}Po/^{210}Pb$ activity ratio "can be greater than one if there are certain marine sources involved". Given the western coastal position of this sampling site and the south-westerly prevailing winds, a marine source is certain for this site. It is possible that radionuclides dissolved in the surface waters of the ocean are incorporated into rainfall by aerosol formation at the air-water interface. Since plankton incorporate ^{210}Po preferentially to ^{210}Pb (FISHER *et al.*, 1983) it is possible that the dissolved surface oceanic $^{210}Po/^{210}Pb$ ratio drops during the spring bloom, which should start around March. Thus rain formed from this source could have a $^{210}Po/^{210}Pb$ ratio lower than one. By May the bloom in production has exhausted the supply of nutrients and the plankton degrade releasing large amounts of ^{210}Po, leading to a high $^{210}Po/^{210}Pb$ ratio in the water column and thus rainfall. However it is stressed that rainfall radionuclide concentrations can vary greatly depending on age of air mass, oceanic or terrestrial source, duration and magnitude of rainstorm and other climatic factors (BASKARAN *et al.*, 1993). These six samples are neither statistically representative of yearly rainfall, nor have they been checked for other variations apart from season, such as wind direction.

There is a large variation in the rainfall radionuclide activities, with no apparent pattern or correlation with magnitude of rainfall. NEVISSI (1987) found no correlation between ^{210}Pb atmospheric flux and magnitude of rainfall, in a seven year study of rainfall to the Seattle area. The mean ^{210}Pb and ^{210}Po activities of 53.8 ± 15.2 and 97.5 ± 107.1 Bq m^{-3} respectively, result in mean depositional fluxes to the whole catchment of 118 ± 40 and 214 ± 230 Bq m^{-2} $year^{-1}$. These are compared with other author's estimates by various methods in **Table 4.2.4.**

The mean ^{210}Pb flux to Kilmore is greater than is found in other coastal sampling sites at the west of continents. This may reflect inaccuracy in the flux determination from so few samples, or the higher than average rainfall for the Etive area. The mean ^{210}Po flux to Kilmore is ten times greater than the only other ^{210}Po determinations I have encountered, however these are for a central continental area. While it is possible that the large ^{210}Po activity in the 22.5.92 sample is unrepresentative of the rest of the year, it is more likely that a rain from a continental source contains far less ^{210}Po than that from a marine source. Over continents the source of ^{210}Po in rainfall will be via decay from ^{222}Rn gas with an additional component from dust particles swept into the air (TUREKIAN *et al.*, 1977). Over the ocean however aerosols may form at the air-water interface, and these may contain high quantities of ^{210}Po.

Table 4.2.4. Comparison with literature ^{210}Pb and ^{210}Po atmospheric deposition fluxes estimated via various methods. ^{210}Po is almost never determined in rainfall as its short half-life requires short sample collection times. The range of values for direct rainfall measurement are time-series variations, while the sediment core derived depositional results are from different stations in the lochs.

	atmospheric flux (Bq m^{-2} yr^{-1})		
Location	**^{210}Pb**	**^{210}Po**	**Reference**
determined via direct rainfall measurement:			
Kilmore, Oban	118 ± 33.5	214 ± 235	this study
Milford Haven, UK	85	-	THOMSON *et al.*, 1993
Plymouth, UK	68	-	CLIFTON, 1991
Zurich, Switzerland	138 (24-430, n=23)	-	SCHULER *et al.*, 1991
Seattle, Wa, USA	73 (27-133, n=7)	-	NEVISSI, 1987
north central Wi, USA	266 (92-462, n=8)	22.2	TALBOT & ANDREN, 1983, 1984
Madison, Wi, USA	-	12 (112-285, n=6)	FRANCIS *et al.*, 1970
Galveston, Tx, USA	172 (112-285, n=3)	-	BASKARAN, *et al.*, 1993
New Haven, Ci, USA	170 (143-285, n=3)	-	BENNINGER, 1978
determined via lake sediment core inventory:			
R. Loch of Glenhead SW. Scotland	95, 83	-	BRYANT, 1993
Loch Lomond, Scotland	72, 152	-	BRYANT, 1993
Loch Coire nan Arr, NW. Scotland	168	-	BRYANT, 1993
Lake Michigan, USA (N to S transect)	140, 118, 100, 63, 67, 240, 52	-	ROBBINS & EDGINGTON, 1975
Inventory in peat core:			
Flanders Moss, central Scotland	90	-	SUGDEN, 1993
North Uist, Hebrides	150	-	SUGDEN, 1993

Each method of estimating the atmospheric ^{210}Pb or ^{210}Po flux has errors associated with it as discussed in detail by TUREKIAN *et al.*, (1977). Firstly the atmospheric flux is highly variable as the concentration of each sample depends on a complex array of variables. Indeed several workers have found a large part of the integrated yearly deposition to be due to single rain events (e.g. BASKARAN *et al.*, 1993). To obtain a statistically valid estimation of the flux by direct measurement, a large number of samples must be taken and a weighted average ^{210}Pb concentration calculated.

The use of 'natural collectors' can integrate this variable flux, and the atmospheric deposition can be inferred from the excess inventories of the radionuclides. In lake sediments however redepositional processes affect the flux, either chemical interactions with different sediment types, or physical redistribution of sediments, or erosion of ^{210}Pb-containing soil from the catchment, as shown in **Table 4.2.4.** by the differing fluxes from cores taken from different parts of freshwater bodies. Since most deposited ^{210}Pb will be trapped in organic rich top soil, undisturbed profiles can give estimates of the ^{210}Pb flux, however since the supported ^{210}Pb will be less than that given by ^{226}Ra measurement due to ^{222}Rn loss, these will be underestimations.

Comparison of atmospheric and riverine inputs

The total input of freshwater to Loch Etive was determined from the rainfall and river flow records, and these values were multiplied by the average river and rainfall ^{210}Pb and ^{210}Po activities to estimate their flux to the surface of Loch Etive. If the riverine input is spread evenly over the entire loch area, then it would average 164 ± 138 and 532 ± 381 Bq m^{-2} yr^{-1} for ^{210}Pb and ^{210}Po respectively, although it should be stressed that the actual input may be significantly higher in some parts of the loch and significantly lower in others. The atmospheric input averaged 118 ± 33.5 and 214 ± 235 Bq m^{-2} yr^{-1} for ^{210}Pb and ^{210}Po respectively. The riverine to atmospheric input ratio is thus 1.4 for ^{210}Pb and 2.5 for ^{210}Po. Atmospheric input is usually the dominant source of ^{210}Pb and ^{210}Po to aquatic systems, but Loch Etive's exceptionally large catchment area enhances the riverine flux. It is possible that the greater importance of ^{210}Po in riverine inputs reflects the short atmospheric residence time of the aerosols carrying the nuclides, compared to decay through the very long-lived ^{210}Pb to ^{210}Po.

Catchment area residence time

As discussed in **Chapter 1.3.** the atmospheric flux of ^{210}Pb is efficiently scavenged by organic horizons in soils even at low pH (LEWIS, 1977). The only way that ^{210}Pb can be lost to the water system is via erosion of particulate material. The removal of radioactivity from a watershed by erosion is generally considered to be first order (DOMINIK *et al.*, 1987) i.e. the removal rate is proportional to the nuclide inventory. Since ^{210}Pb and ^{210}Po are continually supplied by rainfall the system is at steady-state. A simple first-order steady-state model was applied, using the following expression from DOMINIK *et al.*, (1987):

$$\tau r = \frac{(FA - FR)}{(\lambda . FR)} \qquad \textbf{Eqn. 4.2.1.}$$

where τ_r is the catchment area residence time for the nuclide with respect to erosion, F_A is the atmospheric flux of nuclide, F_R is the total riverine flux of nuclide, and λ is the decay constant. This gives a τ_r for ^{210}Pb of 1200 years. This compares with ^{210}Pb residence times of 2000 years in the Susquehanna River catchment, PA (LEWIS, 1977), and 1400 years in the alpine Rhône catchment, Switzerland (DOMINIK *et al.*, 1987).

4.3. ^{210}Pb/^{210}Po in Loch Etive water samples

The water-column particulate, dissolved and total ^{210}Pb and ^{210}Po concentrations, measured at the deep station are tabulated in Appendix **B6.4.** Unfortunately there was insufficient time or resources to complete the ^{210}Pb determination for the final six months of the study. The ^{210}Pb and ^{210}Po profiles and Po/Pb ratios for November '90 to October '91 are plotted versus depth in **Figs. 4.3.1-4.3.5.** Only the ^{210}Po activities for November '91 to June '92 are plotted versus depth in **Fig. 4.3.6.**

The activities found are generally low and constant, around 0.2 Bq m^{-1}, in both dissolved and particulate phases for both nuclides. They are similar to those found in other coastal environments (see **Table 4.3.1.**), in both magnitude and relative partitioning between the phases. In oceanic samples however, most ^{210}Pb is contained in the dissolved phase (BACON *et al.*, 1976) due to the scarcity of particulate material.

Table 4.3.1. Comparison with literature ^{210}Pb and ^{210}Po water activities. Entries in form: mean; standard deviation; range; number of samples. Sampling in Narragansett and Funka Bays was seasonal.

Location	partic. ^{210}Pb (Bq m^{-3})	diss. ^{210}Pb (Bq m^{-3})	total ^{210}Pb (Bq m^{-3})	Reference
Surface water, Loch Etive	0.53 ± 0.29 (0.05-1.17, n=27)	0.34 ± 0.28 (0.09-1.10, n=25)	0.87 ± 0.49 (0.30-2.09, n=25)	This study
Deep waters, Loch Etive	0.17 ± 0.09 (0.08-0.42, n=43)	0.18 ± 0.14 (0.05-0.72, n=43)	0.36 ± 0.20 (0.13-1.14, n=42)	This study
Narragansett Bay, Ri, USA	0.90 ± 0.96 (0.0-2.93, n=6)	0.88 ± 0.61 (0.15-1.92, n=6)	2.23 ± 1.37 (0.63-4.15, n=8)	SANTSCHI *et al.*, 1979
Funka Bay, Japan	–	–	0.99 ± 0.40 (0.32-1.87, n=43)	TANAKA *et al.*, 1987
Yellow Sea, China	–	–	13.02 ± 3.75 (6.67-20.17, n=11)	NOZAKI *et al.*, 1991
Black Sea	0.15 ± 0.09 (0.04-0.29, n=15)	0.56 ± 0.36 (0.11-1.16, n=15)	0.71 ± 0.39 (0.15-1.29, n=15)	WEI & MURRAY, 1994
N. Atlantic,	0.004 ± 0.001 (0.003-0.006,n=11)	0.119 ± 0.029 (0.087-0.177,n=12)	0.123 ± 0.029 (0.091-0.180,n=12)	RITCHIE & SHIMMIELD, 1991
Location	**partic. ^{210}Po** (Bq m^{-3})	**diss. ^{210}Po** (Bq m^{-3})	**total ^{210}Po** (Bq m^{-3})	**Reference**
Surface water, Loch Etive	0.74 ± 0.60 (0.14-2.73, n=43)	0.67 ± 0.67 (0.19-3.95, n=40)	1.36 ± 0.95 (0.47-4.19, n=43)	This study
Deep waters, Loch Etive	0.15 ± 0.07 (0.05-0.36, n=71)	0.27 ± 0.19 (0.10-1.20, n=64)	0.42 ± 0.20 (0.13-1.34, n=73)	This study
Narragansett Bay, Ri, USA	0.88 ± 0.44 (0.12-1.43, n=8)	0.25 ± 0.27 (0.0-0.82, n=8)	1.30 ± 0.69 (0.33-2.67, n=10)	SANTSCHI *et al.*, 1979
Funka Bay, Japan	–	–	0.72 ± 0.23 (0.23-1.15, n=43)	TANAKA *et al.*, 1987
Yellow Sea, China	–	–	3.47 ± 1.47 (1.33-6.50, n=11)	NOZAKI *et al.*, 1991
Black Sea	1.13 ± 0.96 (0.28-3.20, n=15)	0.30 ± 0.19 (0.10-0.66, n=15)	1.42 ± 1.10 (0.38-3.56, n=15)	WEI & MURRAY, 1994
N. Atlantic,	0.51 ± 0.36 (1.58-0.10, n=11)	–	–	RITCHIE & SHIMMIELD, 1991

There have been very few published studies of dissolved and suspended particulate ^{210}Pb and ^{210}Po concentrations in coastal waters, unlike the oceanic environment where a wealth of information exists. This is the first study to look at the seasonality in ^{210}Pb and ^{210}Po cycling in coastal waters in great detail. The only previous study was that of SANTSCHI *et al.* (1979), who reported a seasonal variation in both ^{210}Pb and ^{210}Po, in all three phases, in the surface waters of Narragansett Bay, MA, USA. High radionuclide activities were found in summer, and lower activities in winter.

They attributed this to either radionuclide remobilisation out of the sediments in summer, or the formation of dissolved organic-radionuclide complexes or colloids, which would keep the radionuclides in solution.

Generally ^{210}Po is in excess over ^{210}Pb in every month. There is only a dissolved ^{210}Pb excess in all the December '90 samples, in the 30-70 m samples in November '90, 70-110 m in April '91 and in the 5, 10 and 90 m samples in September '91. The only particulate ^{210}Pb excess is in the 50 m sample in December 90 and the 30-70 m samples in September '91. There is a small increase in particulate ^{210}Pb and ^{210}Po concentration in the bottomost sample in some months but not others. This is attributable to an increase in particle concentration in these samples due to proximity to the sediment-water interface. As mentioned in **2.6.** the actual depth at the Deep Station fixed mooring varied from month to month. The months where there is no concentration increase at 110 m, are those where 110m was not within metres of the bottom. A more consistent approach would have been to alter the depth of the deepest sample each month so that it was a fixed depth from the bottom.

Some of the spring and early summer deep samples have high dissolved ^{210}Po activities. In the samples from 110 m (Feb. '91), 50, 70, 90 and 110 m (Mar '91), and 70 m (Apr. '91) the dissolved ^{210}Po activity can range from 0.5-1.0 Bq m^{-3}. Most notably in the 90 m sample in May '91, the concentration of ~3.4 Bq m^{-3} is 17 times greater than the usual low value. These increases in dissolved ^{210}Po are also depicted in the ^{210}Po inventory results below (**Table 4.3.3.**). Possible explanations for these spring increases in dissolved ^{210}Po are re-mineralisation of ^{210}Po-rich plankton detritus, or re-mobilisation of ^{210}Po from slope sediments followed by lateral transport to the mid basin.

As discussed in **1.3.** ^{210}Po is concentrated in plankton relative to ^{210}Pb. During the spring bloom a deficit of dissolved ^{210}Po relative to its parent should be seen in the surface waters. Conversely there should be an excess of particulate ^{210}Po. There is no evidence of this in the Po/Pb ratio results in **Figs. 4.2.1-5.** possibly because fresh inputs of ^{210}Po dominate. As fecal pellets and plankton debris fall through the water column they decay, and ^{210}Po may be released to the water column, regenerating in a similar manner to nutrients (KADKO, 1993). However there are no peaks in either silicate or phosphate concentration in any of the samples where a peak in dissolved ^{210}Po is detected.

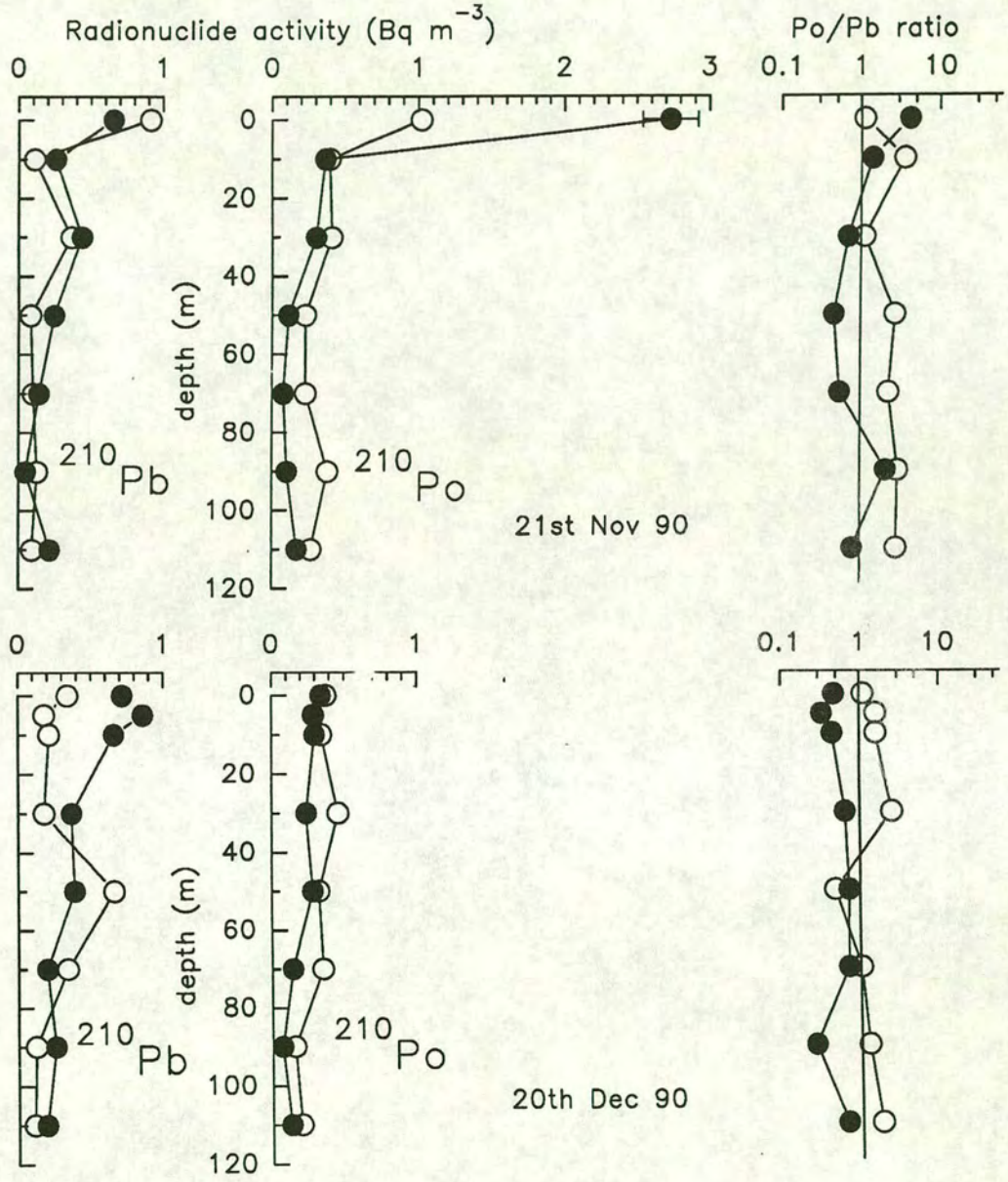


Figure 4.3.1. Particulate ● , and dissolved ○ , ^{210}Pb and ^{210}Po activities at Loch Etive deep station on November 21st (top) and December 20th 1990. Horizontal error bars representing uncertainty in radionuclide determination, mainly from counting statistics, are shown where larger than symbol size.

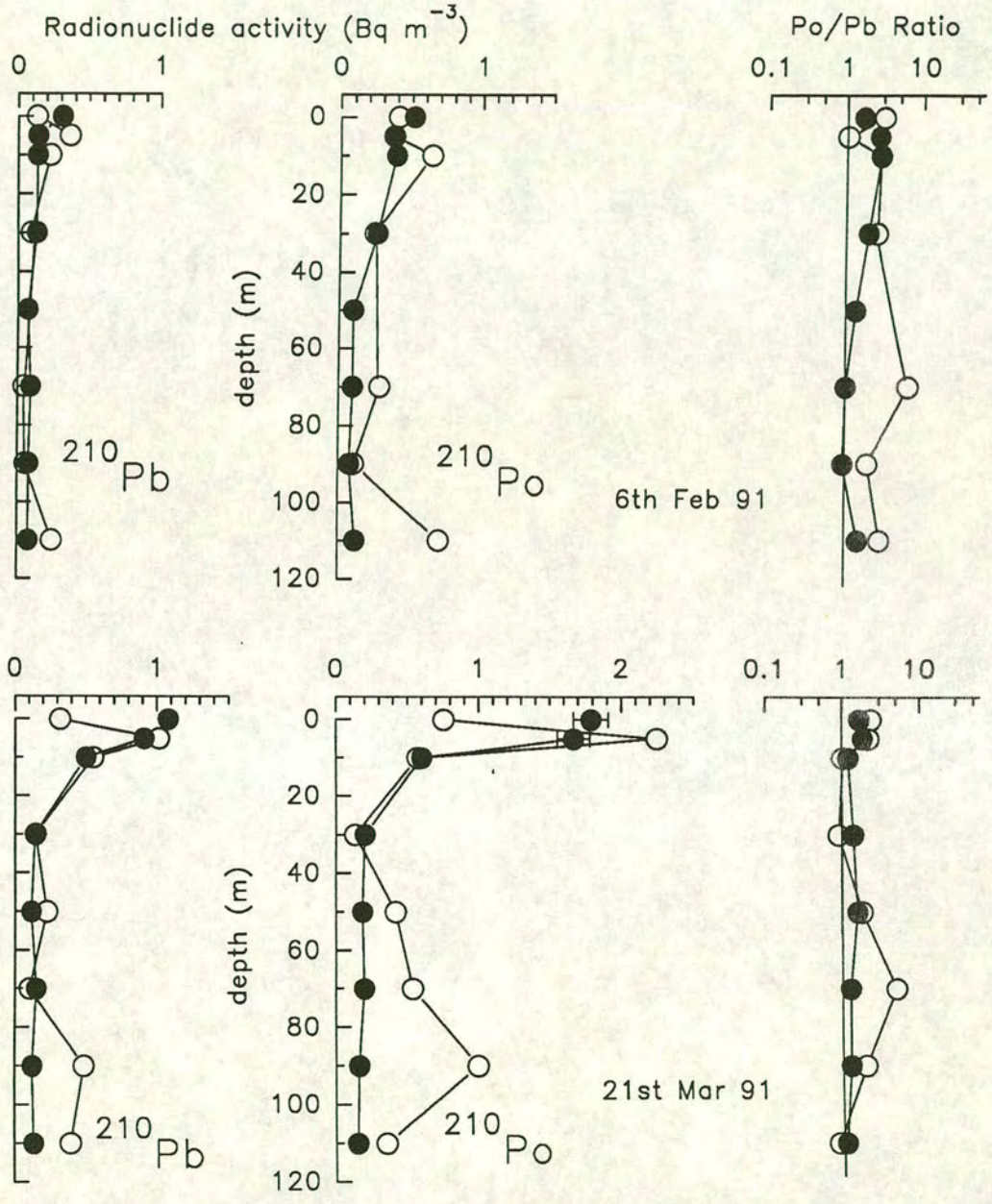


Figure 4.3.2. Particulate ● , and dissolved ❍ , ^{210}Pb and ^{210}Po activities at Loch Etive deep station on February 6th (top) and March 22nd 1991. Horizontal error bars as Fig. 4.2.1.

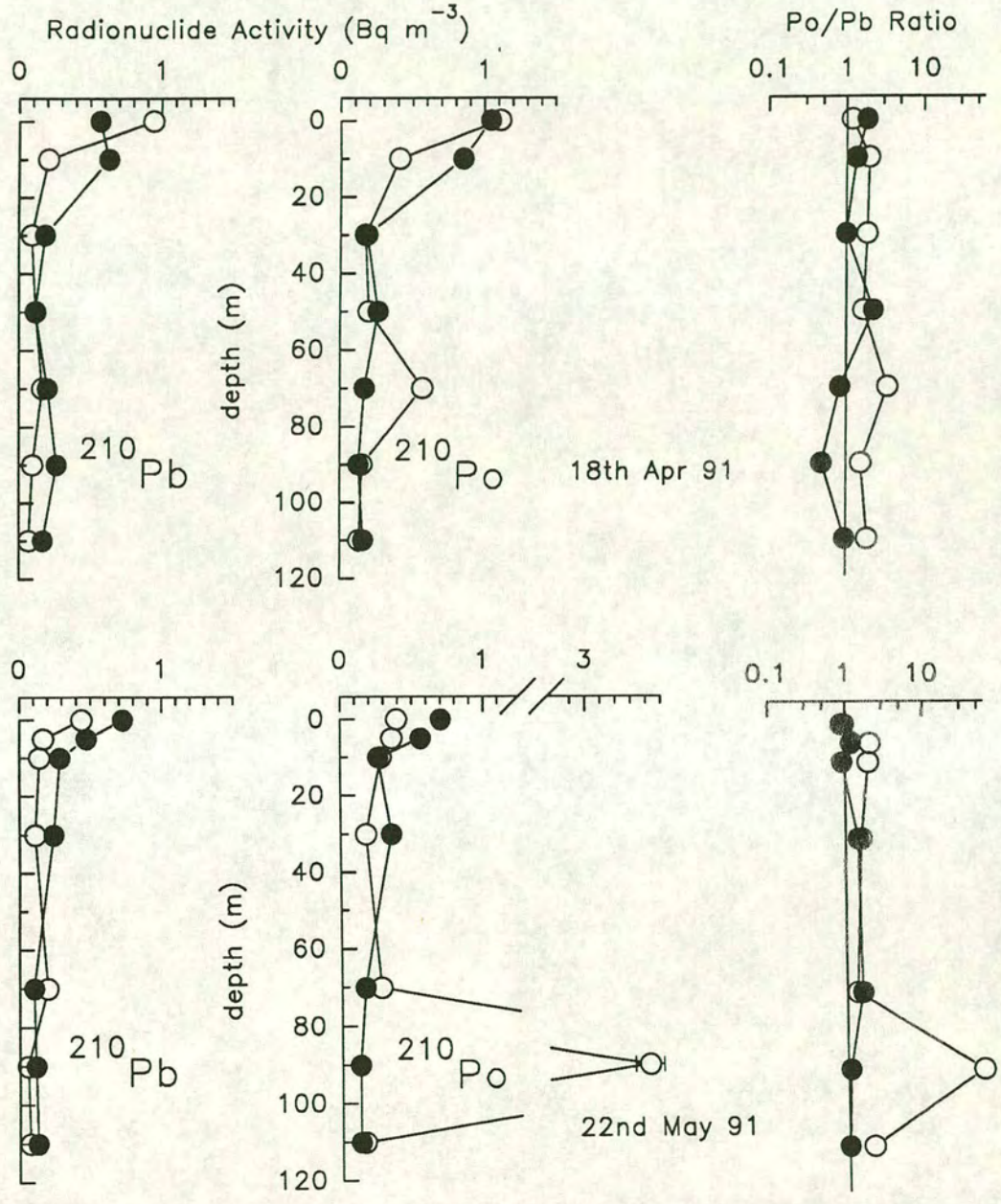


Figure 4.3.3. Particulate ● , and dissolved ○ , ^{210}Pb and ^{210}Po activities at Loch Etive deep station on April 18th (top) and May 22nd 1991. Horizontal error bars as Fig. 4.2.1.

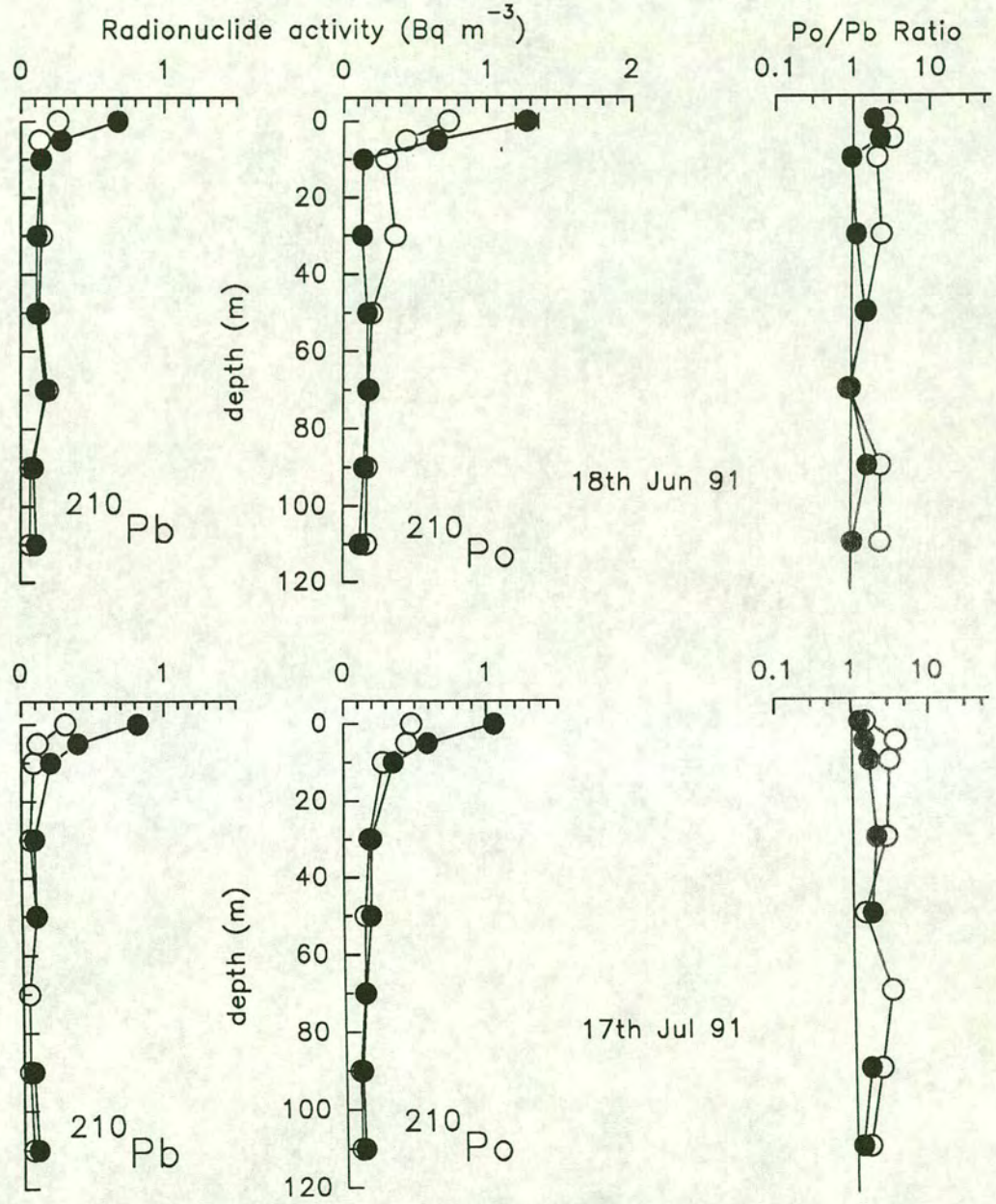


Figure 4.3.4. Particulate ● , and dissolved ❍ , ^{210}Pb and ^{210}Po activities at Loch Etive deep station on June 18th (top) and July 17th 1991. Horizontal error bars as Fig. 4.2.1.

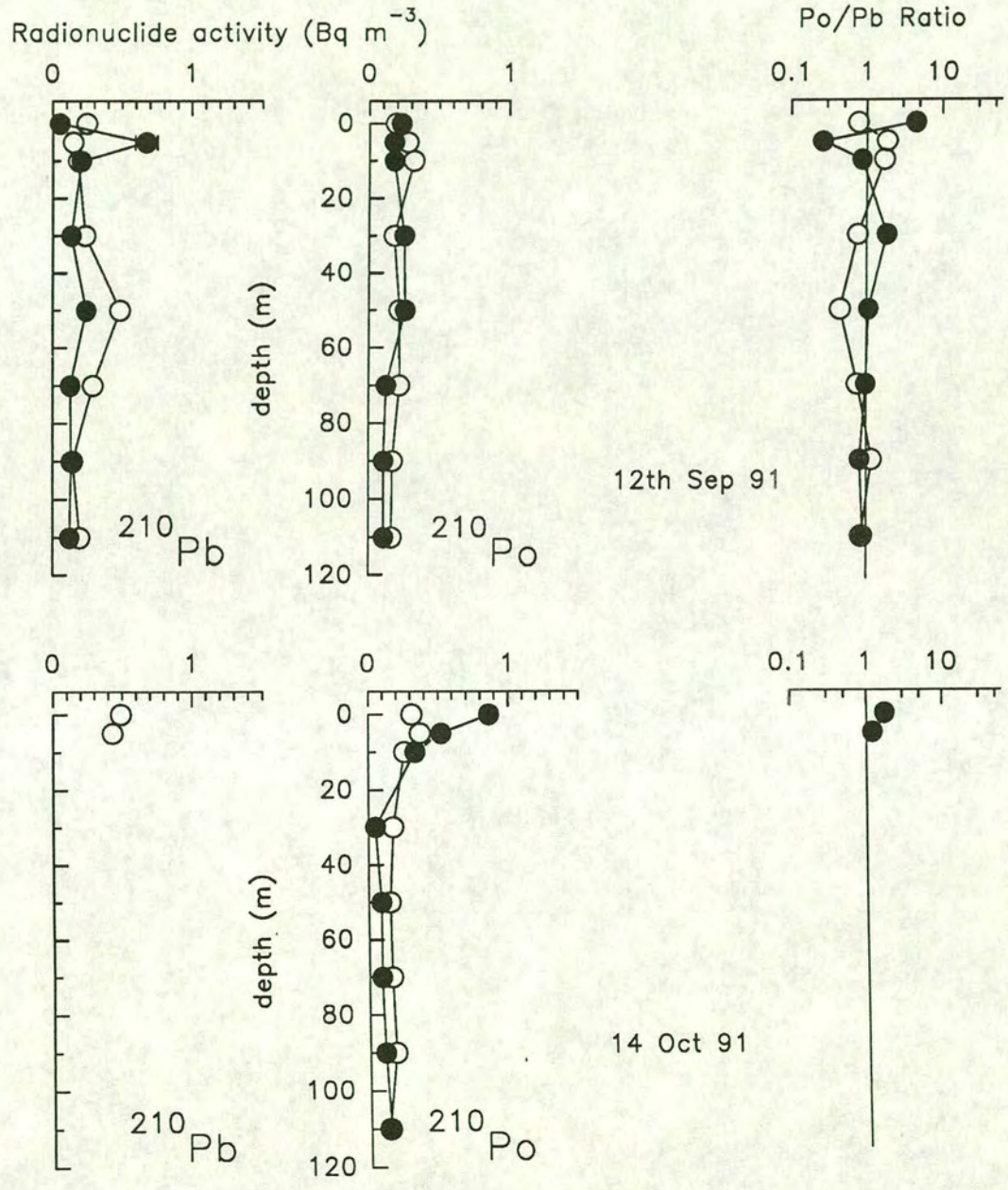


Figure 4.3.5. Particulate ● , and dissolved ❍ , ^{210}Pb and ^{210}Po activities at Loch Etive deep station on September 13th (top) and October 14th 1991. Horizontal error bars as Fig. 4.2.1.

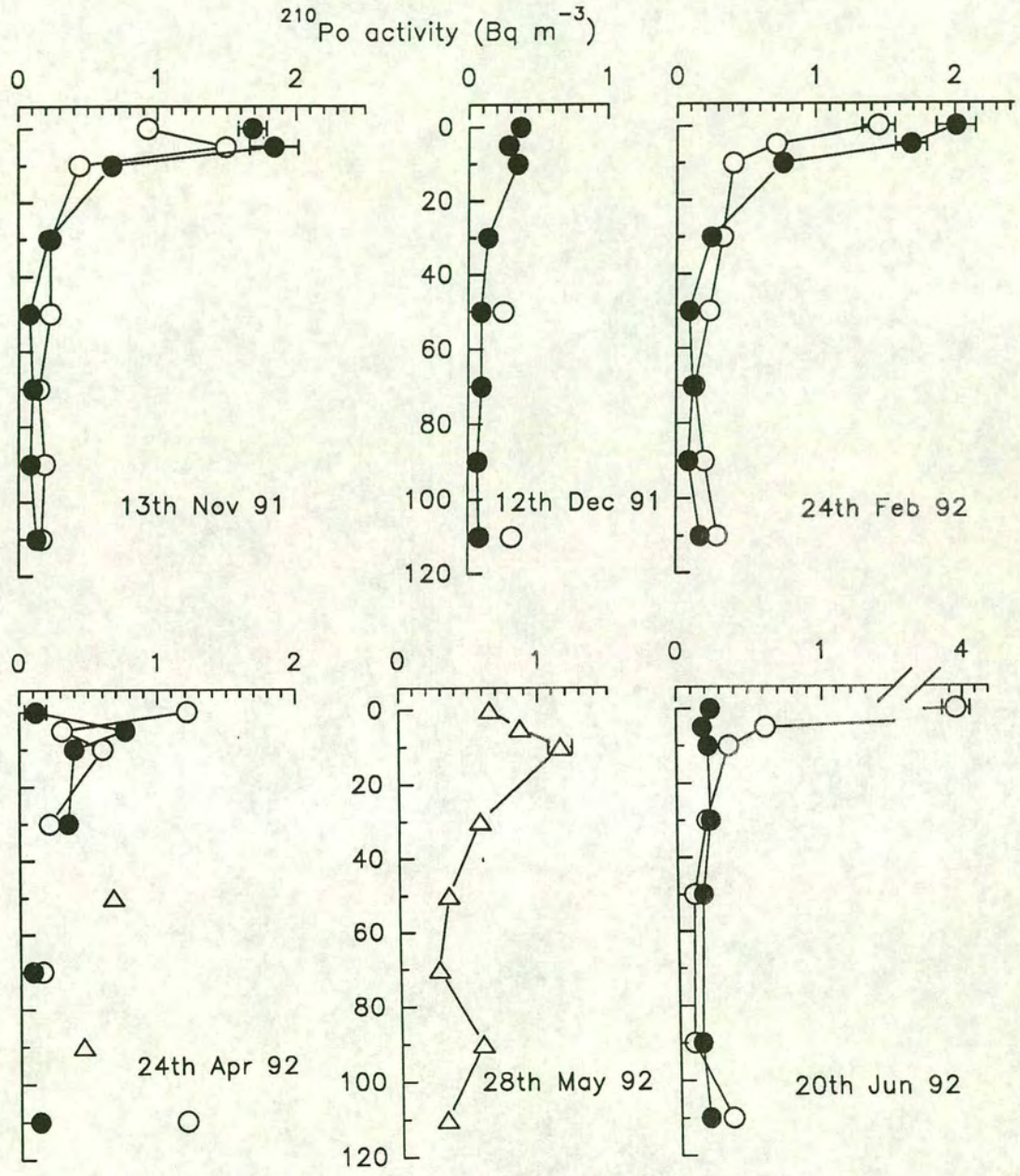


Figure 4.3.6. Particulate ● , dissolved ❍ , and total Δ , Po activities at Loch Etive deep station on November 13th and December 12th 1991, and February 24th, April 23rd, May 28th and June 20th 1992. There are no ^{210}Pb results for these months.

Some of the surface samples (0-10 m) have activities around ten times greater than the normal low activities found in other months. This variation is dependent on the amount of run-off in the preceding weeks, and hence the salinity of the surface water. The dissolved and particulate ^{210}Pb and ^{210}Po surface inventories (0-10 m, see below) have been correlated with run-off (total 16 from **3.2.**) and the surface salinity inventory (0-10 m) and the correlation coefficients (r^2) are tabulated in **Table 4.3.2.** The correlation with run-off is illustrated in **Fig. 4.3.7.** Dissolved ^{210}Pb and particulate ^{210}Po show a good correlation with salinity and run-off, while particulate ^{210}Pb and dissolved ^{210}Po do not. Note that the river particulate/dissolved ratio (**Table 4.2.1.**) averages 0.377 for ^{210}Pb and 0.681 for ^{210}Po. Part of the correlation is thus explained by the fact that river water is rich in dissolved ^{210}Pb and particulate ^{210}Po. There will be further discussion of these correlations in **4.5.**

Table 4.3.2. Surface nuclide inventory correlation coefficients with salinity and run-off.

	dissolved		particulate	
	^{210}Pb	^{210}Po	^{210}Pb	^{210}Po
salinity	- 0.784	- 0.174	- 0.119	- 0.692
run-off	0.677	0.057	0.082	0.539

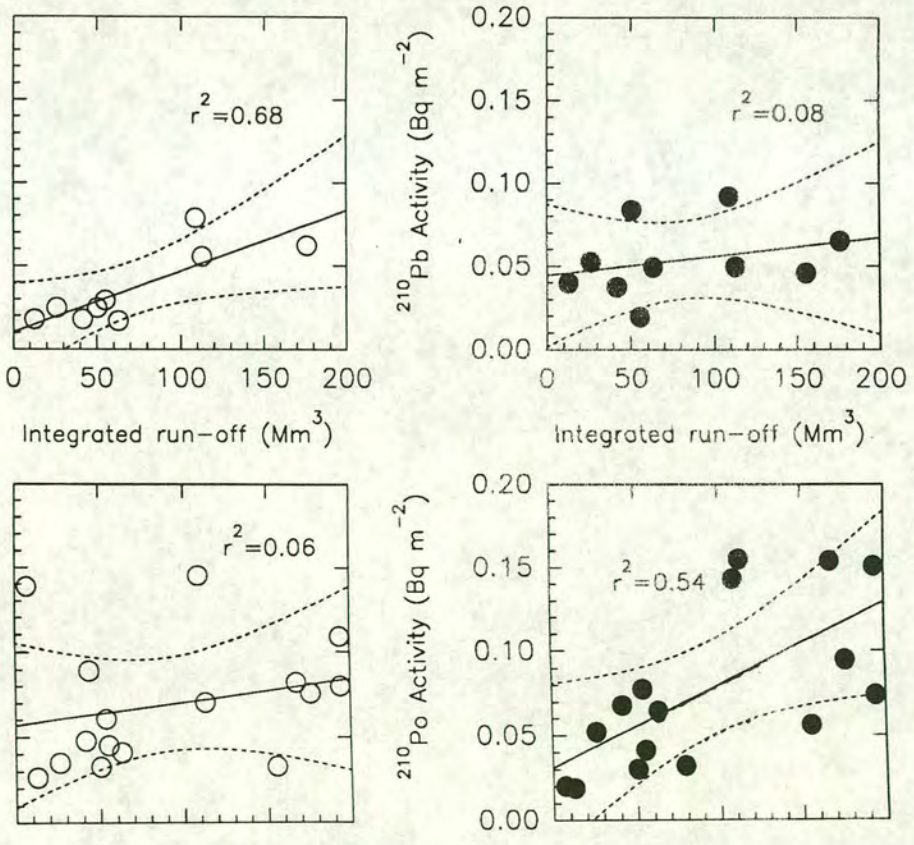


Figure 4.3.7. Correlation of dissolved (○ , ——— , left) and particulate (● , - - - - - , right) surface (0-10 m) inventory of ^{210}Pb (top) and ^{210}Po (bottom) with run-off (see text).

Radionuclide Inventories

Dissolved and particulate ^{210}Pb and ^{210}Po inventories were calculated for the surface (0-10 m), intermediate (10-60 m), deep (60-120 m) and total (0-120 m) layers (see **3.4.**). The results are tabulated in **Table 4.3.3.** The radioactive inventories are plotted versus time in **Figs. 4.3.8.** (Po) and **4.3.9.** (Pb). A considerable monthly variation is apparent in the surface and total layers, due to the run-off caused surface layer variation in radioactivity. The intermediate and deep layer inventories show less variation. The ^{210}Pb inventories are much less variable than those of ^{210}Po. Deep particulate ^{210}Po shows a trend with an increase in spring followed by a slow decline for the rest of the year. The huge increase in deep dissolved ^{210}Po in spring is shown well. Mar '91, May '91 and Apr. '92 have massively increased inventories, while there is no data for Mar or May '92, where a similar increase might be expected. By June in both years the inventory had returned to low values.

Table 4.3.3. Monthly ^{210}Pb and ^{210}Po inventories in the Loch Etive water column.

^{210}Pb	particulate ^{210}Pb inventory (Bq m^2)				dissolved ^{210}Pb inventory (Bq m^2)			
end date	**surface**	**intermed.**	**deep**	**total**	**surface**	**intermed.**	**deep**	**total**
21.11.90	5.0 ± 0.6	17.6 ± 4.1	8.8 ± 2.7	31.4 ± 12.8	5.5 ± 0.3	10.9 ± 1.8	7.0 ± 1.6	23.4 ± 6.8
20.12.90	8.4 ± 0.7	23.5 ± 6.4	14.0 ± 4.9	46.0 ± 20.7	2.5 ± 0.2	20.5 ± 3.4	12.4 ± 3.7	35.4 ± 12.4
6.2.91	2.0 ± 0.2	6.0 ± 1.4	5.6 ± 1.5	13.5 ± 5.1	2.9 ± 0.3	6.0 ± 1.2	7.5 ± 1.9	16.4 ± 5.6
22.3.91	9.2 ± 0.5	11.1 ± 2.3	9.0 ± 2.5	29.3 ± 10.3	7.9 ± 0.7	14.1 ± 3.4	21.4 ± 4.7	43.4 ± 14.6
18.4.91	6.5 ± 0.4	13.3 ± 2.4	13.7 ± 2.4	33.5 ± 8.8	6.2 ± 0.4	6.8 ± 1.4	7.2 ± 1.9	20.2 ± 7.0
22.5.91	5.3 ± 0.6	12.0 ± 2.7	7.5 ± 1.6	24.8 ± 7.9	2.5 ± 0.2	7.2 ± 1.9	7.2 ± 1.8	16.9 ± 6.4
18.6.91	3.8 ± 0.4	6.5 ± 1.5	8.1 ± 2.4	18.3 ± 7.0	1.8 ± 0.2	7.6 ± 1.7	7.1 ± 2.0	16.4 ± 6.1
17.7.91	4.9 ± 0.3	6.5 ± 1.6	5.7 ± 1.5	17.1 ± 6.3	1.7 ± 0.1	4.5 ± 1.0	3.4 ± 0.9	9.6 ± 3.4
12.9.91	4.0 ± 0.5	9.3 ± 1.8	7.6 ± 2.1	20.9 ± 7.5	1.8 ± 0.2	16.0 ± 3.3	12.2 ± 8.7	30.0 ± 8.7
14.10.91	4.4 ± 0.5	-	-	-	-	-	-	-
^{210}Po	particulate ^{210}Po inventory (Bq m^2)				dissolved ^{210}Po inventory (Bq m^2)			
date	**surface**	**intermed.**	**deep**	**total**	**surface**	**intermed.**	**deep**	**total**
21.11.90	15.5 ± 1.3	12.1 ± 2.7	7.0 ± 1.9	34.6 ± 12.5	7.1 ± 0.7	16.8 ± 4.6	17.7 ± 4.0	41.7 ± 15.4
20.12.90	3.0 ± 0.2	13.3 ± 2.5	6.8 ± 1.8	23.2 ± 7.8	3.3 ± 0.2	19.0 ± 3.4	14.1 ± 3.7	36.4 ± 11.9
6.2.91	4.1 ± 0.3	11.2 ± 2.4	5.9 ± 1.9	21.2 ± 8.5	4.5 ± 0.3	16.6 ± 3.3	22.0 ± 5.9	43.1 ± 14.7
22.3.91	14.3 ± 1.0	13.8 ± 3.2	10.2 ± 2.6	38.2 ± 13.7	14.5 ± 0.5	16.7 ± 3.8	37.4 ± 4.9	68.7 ± 18.3
18.4.91	9.5 ± 0.5	17.5 ± 2.7	9.3 ± 2.2	36.3 ± 10.4	7.6 ± 0.5	11.5 ± 3.1	17.3 ± 4.7	36.4 ± 14.2
22.5.91	5.2 ± 0.4	15.0 ± 2.9	8.5 ± 2.0	28.7 ± 9.1	3.5 ± 0.3	11.0 ± 2.1	76.9 ± 13.0	91.4 ± 24.5
18.6.91	6.8 ± 0.5	7.4 ± 1.7	8.6 ± 2.2	22.9 ± 8.0	4.8 ± 0.4	14.3 ± 3.2	10.2 ± 2.6	29.3 ± 10.1
17.7.91	6.5 ± 0.5	11.1 ± 2.3	7.9 ± 2.0	25.5 ± 8.6	4.1 ± 0.2	9.3 ± 1.9	6.9 ± 1.7	20.3 ± 6.5
12.9.91	1.9 ± 0.2	11.5 ± 2.0	6.8 ± 1.6	20.2 ± 6.0	2.7 ± 0.2	11.3 ± 1.8	11.0 ± 3.1	24.9 ± 8.1
14.10.91	5.6 ± 0.4	6.2 ± 1.5	6.9 ± 1.8	18.7 ± 6.8	3.3 ± 0.2	9.2 ± 1.7	9.7 ± 2.2	22.1 ± 6.8
13.11.91	15.1 ± 1.2	12.6 ± 3.2	6.4 ± 1.8	34.1 ± 13.3	10.9 ± 0.7	13.6 ± 3.1	10.1 ± 2.1	34.7 ± 10.8
12.12.91	3.2 ± 0.4	8.2 ± 1.3	4.9 ± 0.9	16.3 ± 4.5	-	12.7 ± 0.0	18.8 ± 0.0	32.8 ± 0.0
24.2.92	15.4 ± 1.6	14.7 ± 2.0	7.7 ± 1.2	37.8 ± 8.7	8.3 ± 0.8	15.7 ± 1.7	12.9 ± 1.6	36.9 ± 7.1
24.4.92	7.8 ± 0.9	15.4 ± 1.6	6.8 ± 1.0	30.0 ± 6.3	6.1 ± 0.6	14.1 ± 1.1	40.8 ± 3.4	61.0 ± 9.0
20.6.92	2.0 ± 0.2	10.6 ± 1.3	10.6 ± 1.6	23.2 ± 5.0	13.9 ± 0.7	10.5 ± 1.1	11.4 ± 1.5	35.7 ± 6.3

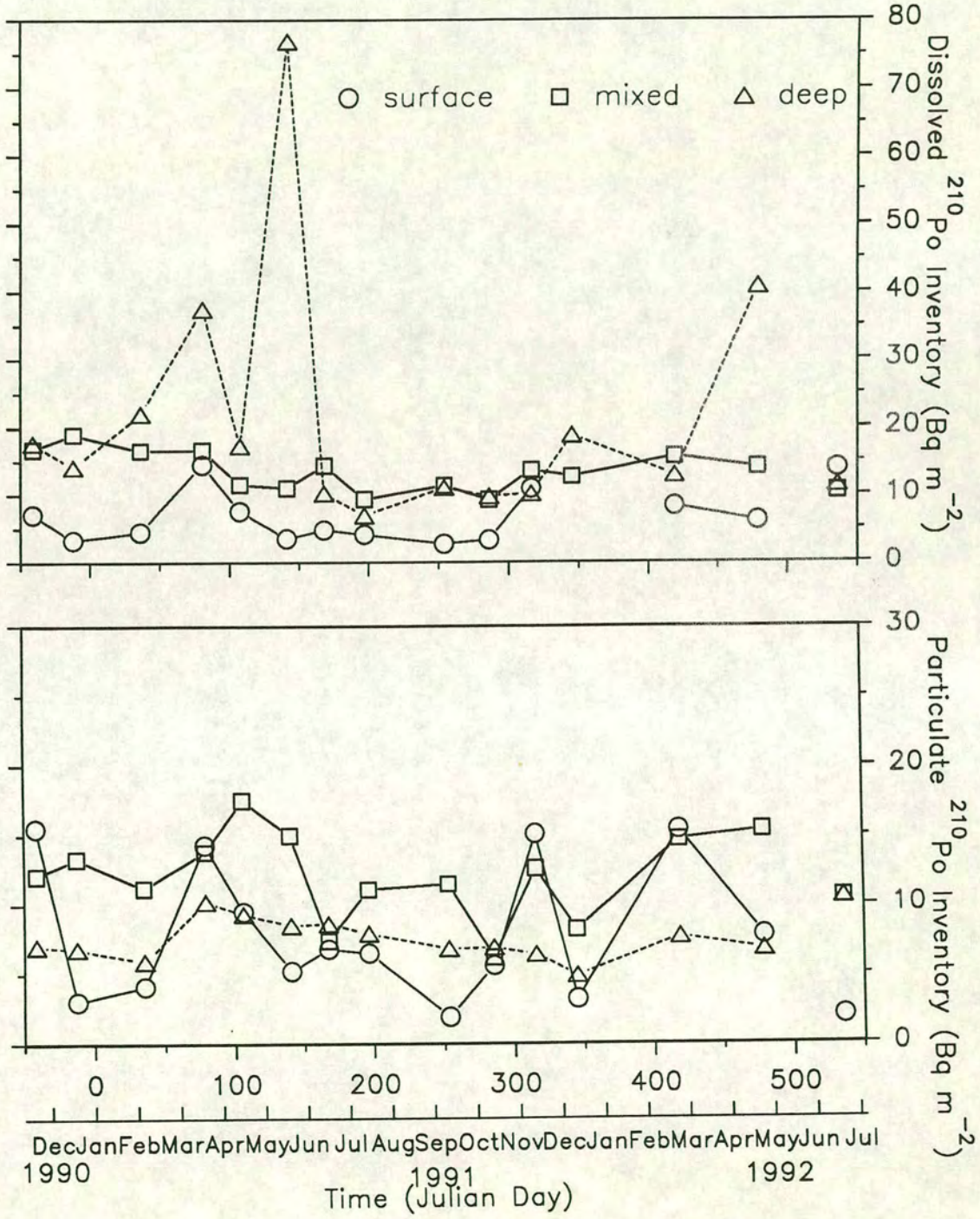


Figure 4.3.8. ^{210}Po dissolved (upper) and particulate (lower) water-column inventories in the surface (—○—), intermediate (—□—) and deep (- - -△- - -) layers of the deep station, Loch Etive.

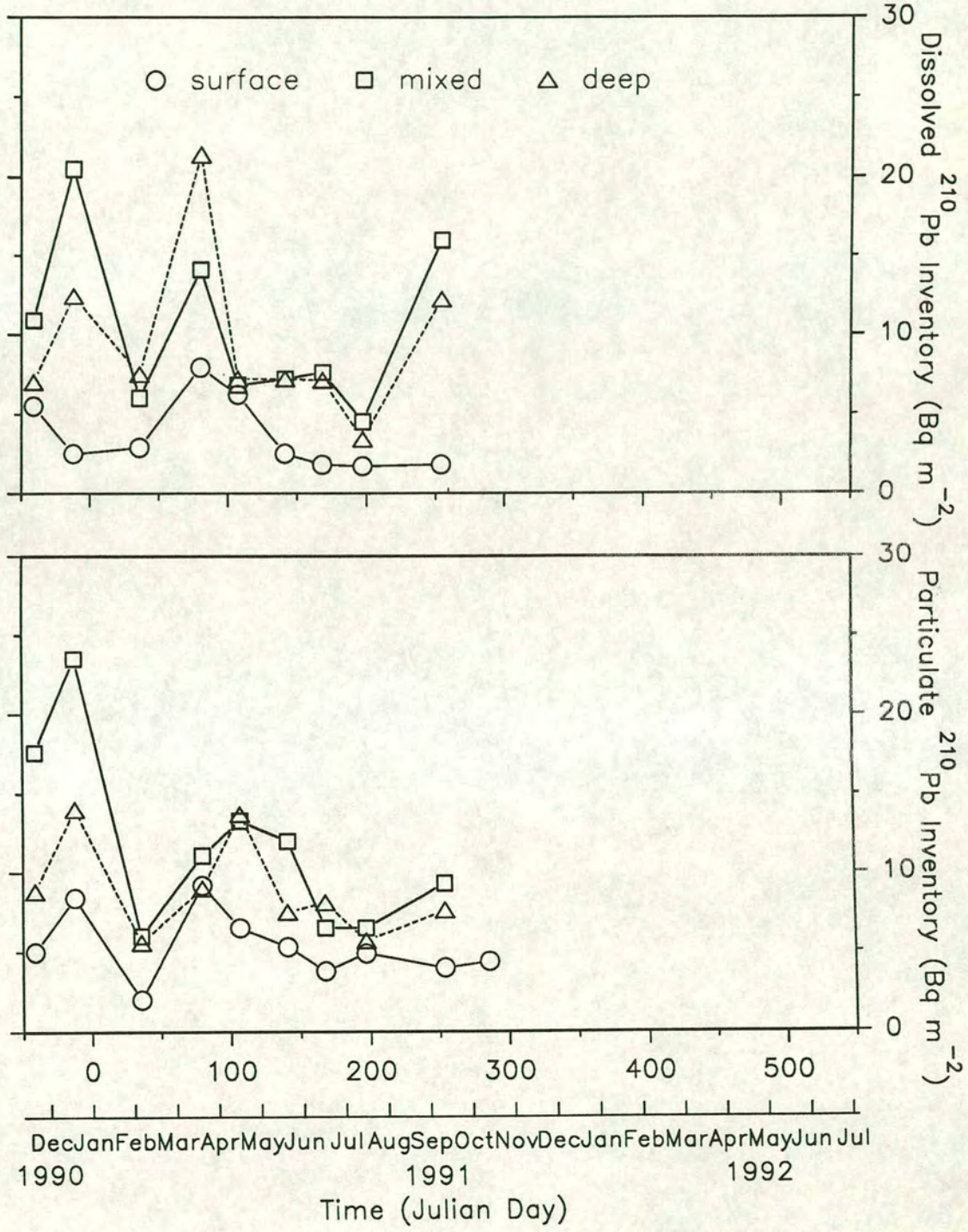


Figure 4.3.9. ^{210}Pb dissolved (upper) and particulate (lower) water-column inventories in the surface (—○—), intermediate (—□—) and deep (- - -Δ- - -) layers of the deep station, Loch Etive.

Radionuclide Residence Times

A non-steady state model was used to estimate the value of the first-order removal coefficient (k_{Pb}) as a function of time. The change in the mean inventory of ^{210}Pb with time:

$$\frac{dA_{Pb}}{dt} = R_{Pb} + \lambda_{Pb}A_{Ra} - (\lambda_{Pb} + k_{Pb})A_{Pb} \qquad \textbf{Eqn 4.3.1.}$$

where A_{Ra} and A_{Pb} refer to the activities of ^{226}Ra and ^{210}Pb respectively (Bq m^{-2}), λ_{Pb} is the radioactive decay constant of ^{210}Pb ($days^{-1}$) and I_{Pb} is the input flux of ^{210}Pb (Bq m^{-2} day^{-1}). The solution to equation 4.3.1. is given by TANAKA *et al.* (1983) as:

$$kPb = \lambda Pb\left[\frac{ARa}{APb1} - 1\right] + \frac{\bar{I}Pb}{APb1} + \frac{1}{T}\left[1 - \frac{APb2}{APb1}\right] \qquad \textbf{Eqn 4.3.2.}$$

which can be used to calculate a value of k_{Pb} for the specific time interval T (the time between the two measurements A_{Pb1} and A_{Pb2} in days). The ^{226}Ra activity was not determined, and was assumed to be 2 Bq m^{-3} (SHIMMIELD, 1993). For the surface layer I was a combination of atmospheric flux and riverine flux, assuming that the riverine input was equally spread over the entire surface. Similarly the first-order removal coefficient for ^{210}Po was estimated from:

$$kPo = \lambda Po\left[\frac{APb}{APo1} - 1\right] + \frac{\bar{I}Po}{APo1} + \frac{1}{T}\left[1 - \frac{APo2}{APo1}\right] \qquad \textbf{Eqn. 4.3.3.}$$

The removal residence time (τ) for ^{210}Pb and ^{210}Po is given by the inverse of k and the monthly values of these are tabulated in **Table 4.3.5.** The residence time was calculated for the surface (0-10 m), intermediate (10-60 m) and deep waters (60-120 m) and for the total water column. The monthly variation in τ demonstrates the varying efficiency and intensity of removal mechanisms for ^{210}Pb and ^{210}Po, which I will discuss in **4.5.**

Table 4.3.4. Literature examples of ^{210}Pb and ^{210}Po residence times (for removal from the water column, i.e. scavenging plus sedimentation).

Location	residence time (days)		Reference
	^{210}Pb	**^{210}Po**	
freshwater:			
Crystal Lake, Wi, USA	35 (16-440, n=8)	95 (n=8)	TALBOT & ANDREN, 1984
Bickford Pond, Ma, USA	41	50	BENOIT & HEMOND, 1987
Lake Zurich, Switzerland	35 ± 12 (20-66, n=10)	300-800	WIELAND *et al.*, 1991
seawater:			
Narragansett Bay, Ri, USA	35 ± 21 (10-64, n=9)	90 ± 60 (27-170, n=8)	SANTSCHI *et al.*, 1979
Funka Bay, Japan	86 (64-130, n=3)	137(117-157,n=3)	TANAKA *et al.*, 1983
Washington coast, USA: 1: Juan de Fuca straight 2: Continental shelf	 58 128	 - -	SCHELL, 1977
Yellow Sea, China: 1: Yangtze River Mouth 2: Shelf-Edge	 15-45 60-200	 35-90 120-400	NOZAKI *et al.*, 1991
N. Atlantic	15-300	400-1200	RITCHIE & SHIMMIELD, 1991

Examples of ^{210}Po and ^{210}Pb residence times from the literature are tabulated in **Table 4.3.4.** Residence times increase as the distance from the coast increases, which reflects the decrease in amounts of particulate matter towards the open ocean (SCHELL, 1977). Generally, considerably longer residence times are found for total ^{210}Po than for total ^{210}Pb in both fresh and salt water environments. SANTSCHI *et al.*, (1979) found ^{210}Pb was removed onto particles more slowly than ^{210}Po in Narragansett Bay, but ^{210}Po was removed from the water column more slowly than ^{210}Pb. They attributed this to greater recycling of ^{210}Po. They also found a pronounced seasonal variation, with the radionuclide removal times rising from ~10 days in winter to ~2 months in summer. WIELAND *et al.*, (1991) also reported residence times slightly greater in summer than in winter, in Lake Zurich. In contrast BENOIT & HEMOND (1987) found radionuclide removal times to be longer in winter than in summer, in Bickford Pond. There were no seasonal patterns apparent in either Crystal Lake (TALBOT & ANDREN, 1984) or Funka Bay (TANAKA *et al.*, 1983). BASKARAN & SANTSCHI (1993) appeared to find greater ^{210}Pb residence times in spring than in summer and winter, in estuaries and bays of Texas, but they point out that the limited data set made it impossible to tell whether this was an effect of

seasonality or particle cycling intensity. I am aware of no other studies of the seasonal variation in residence time for ^{210}Po and ^{210}Pb.

In Loch Etive the ^{210}Po residence times (plotted in **Figure 4.3.10.**) are generally shorter than the ^{210}Pb residence times (**Figure 4.3.11.**), which is the opposite of that found in many other areas. The residence times of both nuclides are also generally shorter than other comparable areas, which perhaps reflects higher particulate concentrations from the large catchment area of Loch Etive.

Several points of interest may be noted. There was a spring maximum in the deep layer dissolved ^{210}Po residence time which reflects an increase in the recycling of ^{210}Po, either due to the remineralisation of sedimenting organic particles, or the remobilisation of ^{210}Po from the sediment. No deep layer dissolved ^{210}Po residence time is reported for May '91 as the huge excess ^{210}Po in this month gave a large negative number. There was an increase in the residence time of surface layer dissolved and particulate ^{210}Pb and ^{210}Po in April '91, presumably due to recycling of plankton in the early part of the spring bloom. There was a maximum in the intermediate layer dissolved and particulate ^{210}Pb residence time in winter '90-'91. This may be due to a small sedimenting particulate flux during the winter, as the sediment trap dry mass (**5.1.**) has minimum values during the winter.

Table 4.3.5. Monthly scavenging and particle removal times for the Loch Etive water column.

^{210}Pb	scavenging residence time (days)				sedimentation residence time (days)			
end date	**surface**	**intermed.**	**deep**	**total**	**surface**	**intermed.**	**deep**	**total**
20.12.90	9.7	76.9	24.2	330.2	14.2	65.5	29.9	-126.1
6.2.91	2.3	14.5	10.2	23.3	6.8	15.9	10.9	37.1
22.3.91	5.9	14.0	24.9	1333.6	4.4	12.0	10.3	-86.3
18.4.91	6.6	10.0	12.8	21.6	7.5	10.5	9.3	39.3
22.5.91	24.1	48.0	45.8	77.1	35.2	69.1	40.4	104.0
18.6.91	6.7	21.2	20.1	44.4	13.1	21.5	22.5	67.3
17.7.91	3.6	12.5	11.3	22.0	8.3	13.0	13.9	44.3
12.9.91	6.0	49.8	24.4	-174.9	16.4	26.9	21.9	-217.9
^{210}Po	scavenging residence time (days)				sedimentation residence time (days)			
end date	**surface**	**intermed.**	**deep**	**total**	**surface**	**intermed.**	**deep**	**total**
20.12.90	5.3	15.2	13.8	32.0	9.7	10.1	5.7	21.7
6.2.91	1.1	6.5	5.2	13.2	1.0	4.5	2.3	7.6
22.3.91	3.4	11.0	19.2	50.5	3.1	7.5	4.0	18.6
18.4.91	4.5	5.3	10.3	17.0	4.6	4.9	3.4	12.7
22.5.91	15.4	30.9	-12.1	-27.7	19.3	40.3	21.8	61.3
18.6.91	4.5	16.2	26.1	33.3	6.8	13.8	10.5	28.2
17.7.91	4.0	10.7	7.9	20.4	5.7	7.0	7.1	21.1
12.9.91	5.8	14.7	11.5	36.4	8.4	16.8	11.2	34.3
14.10.91	0.9	3.5	3.5	7.7	0.6	3.5	2.2	6.4

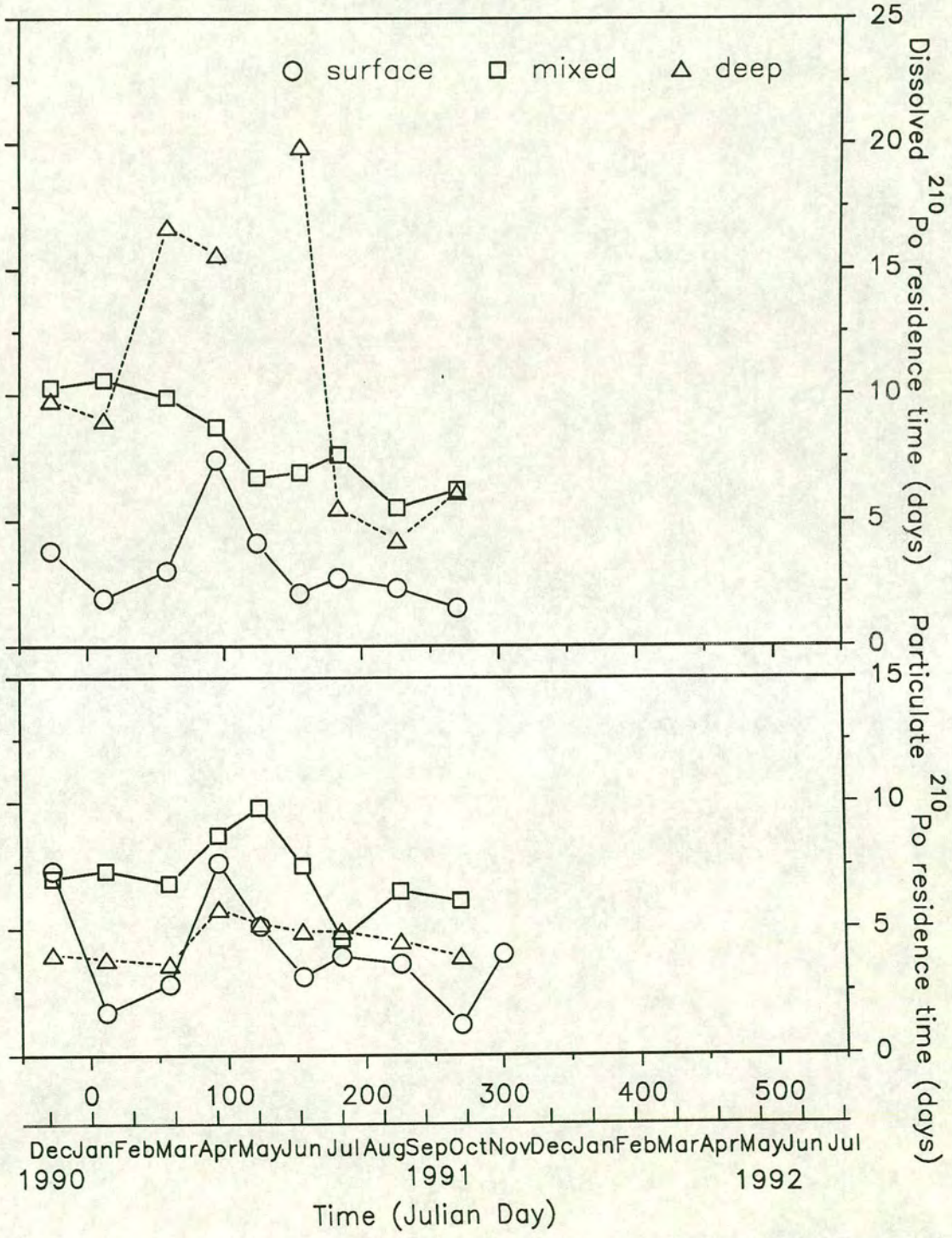


Figure 4.3.10. ^{210}Po dissolved (upper) and particulate (lower) water-column residence times in the surface (—○—), intermediate (—□—) and deep (- - -△- - -) layers of the deep station, Loch Etive.

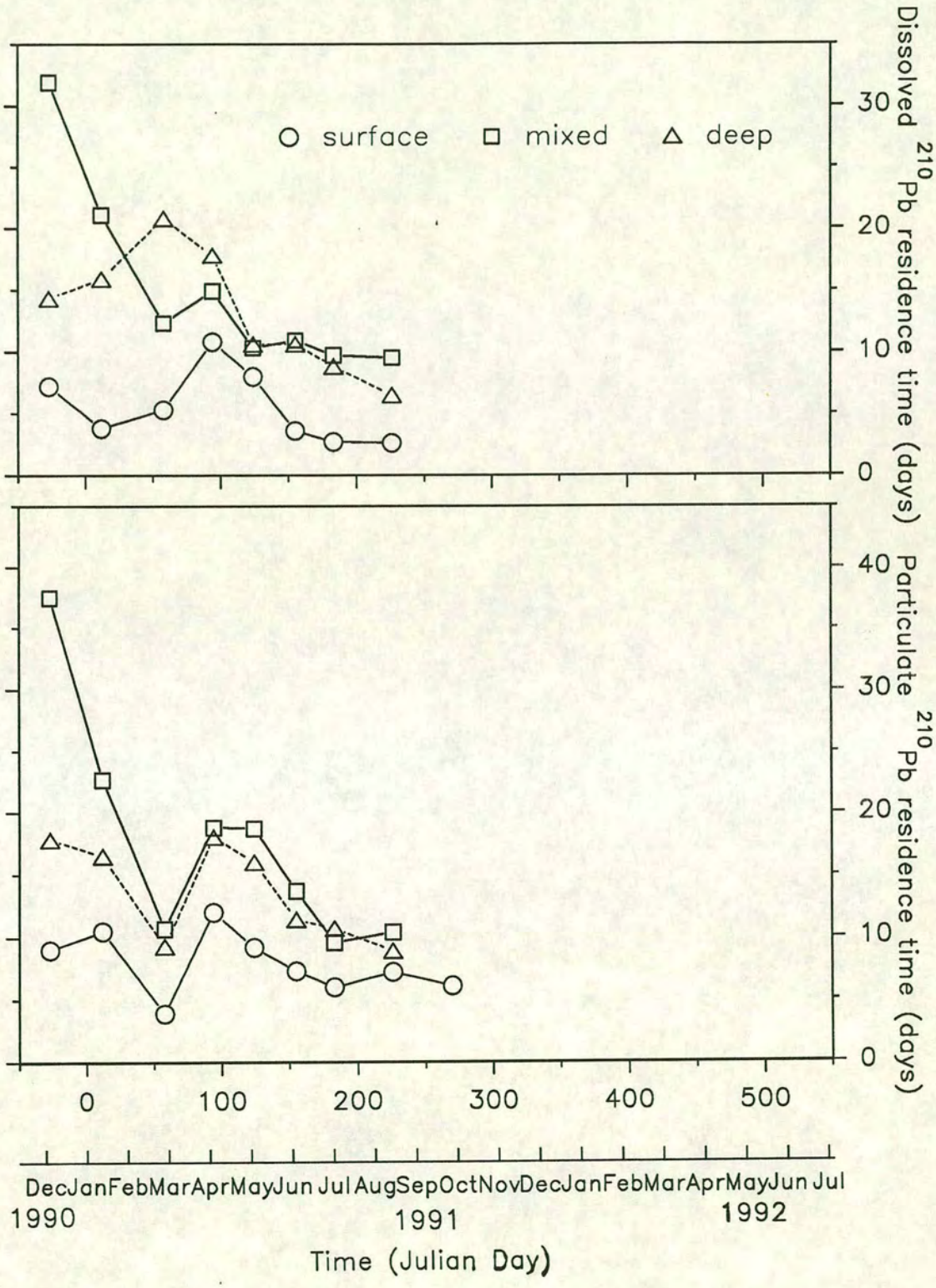


Figure 4.3.11. ^{210}Pb dissolved (upper) and particulate (lower) water-column residence times in the surface (—○—), intermediate (—□—) and deep (- - -△- - -) layers of the deep station, Loch Etive.

Comparison of SAP with bottle samples

Eight SAP particulate filters were digested, and ^{210}Pb and ^{210}Po determined by alpha spectrometry to provide a comparison between bottle sampling and SAP sampling. RITCHIE & NEWTON (1991) found that SAPs significantly undersample in comparison to bottle samples. They suggested that a proportion of particulate radionuclide activity is lost onto the filter assembly, possibly by back filtration or disturbance during SAP recovery. The walls of the filter assembly were wiped with a paper tissue after sampling, and the ^{210}Pb and ^{210}Po activity on the tissue was determined to estimate loss of radionuclides to the SAP system. RITCHIE & NEWTON (1991) also noted that the discrepancy between bottles and SAPs was less when cellulose ester (Azypor) filters were used as opposed to polycarbonate membrane (Nucleopore) filters. They suggested that the higher loading capacity of the Azypor filter enabled more particulate matter to be retained. In this study Azypor filters were used throughout.

The results in **Table 4.3.6.** show no systematic differences between the methods for ^{210}Pb, with a mean SAP/bottle ratio of 1.05 ± 0.25, and for ^{210}Po in September '91: SAP/bottle ratio is 1.01 ± 0.35. However the ^{210}Po activity was lower in the SAP samples than the bottle samples in June '91: SAP/bottle ratio is 0.83 ± 0.05. The activity retained on the filter hats is insufficient to account for the difference: mean wipe tissue activity 0.011 ± 0.002 Bq m^{-3}. There is wide variation in the SAP/bottle ratio with depth; it may be possible that some types of particles are retained on the filters better than others. Thus planktonic particles found in the upper waters may be easily lost, while Mn and Fe oxyhydroxides found at depth may be oversampled.

Table 4.3.6. Deep Station particulate ^{210}Po and ^{210}Pb activity determined via SAP sampling, and inter-comparison of SAP and bottle results.

		^{210}Po		^{210}Pb	
date	**depth (m)**	**SAP activity (Bq m^{-3})**	**SAP/bottle ratio**	**SAP activity (Bq m^{-3})**	**SAP/bottle ratio**
19.6.91	30	0.108 ± 0.008	0.82	0.109 ± 0.010	0.87
	50	0.132 ± 0.009	0.78	0.137 ± 0.012	1.13
	70	0.156 ± 0.010	0.91	0.148 ± 0.012	0.79
	90	0.115 ± 0.008	0.79	0.137 ± 0.012	1.43
13.9.91	30	0.182 ± 0.016	0.72	-	-
	50	0.162 ± 0.011	0.63	-	-
	70	0.154 ± 0.011	1.22	-	-
	90	0.161 ± 0.012	1.47	-	-

4.4 A mass balance model of ^{210}Po and ^{210}Pb cycling in Loch Etive

The simple mass balance box-model described by BENOIT & HEMOND (1987) was adapted, with the water column split into the three boxes discussed in **3.4.** - surface (0-10 m), intermediate (10-60 m) and deep (60-120 m). The equations are consistent with those of the residence time calculations in **4.3.** A number of assumptions were made:

- the riverine input was spread evenly over the surface of the loch.
- only the surface box receives the riverine and rainfall inputs.
- the rainfall input was only to the dissolved fraction (TALBOT & ANDREN, 1984).
- the inflow and outflow over the entrance sill was balanced.
- the activity of ^{226}Ra in the loch was 2 Bq m^{-3} (SHIMMIELD, 1993).
- there was no ^{226}Ra (hence supported ^{210}Pb) in the particulate fraction.
- only sedimentation transports Pb and Po to the lower boxes.
- eddy diffusion was neglected.

The equations describing dissolved ^{210}Pb and ^{210}Po in the surface box are:

scavenging = river + rain + support - decay - change in storage

$$F_S = \frac{V.C_{Pb}}{A} + C_{Pb}.R + I_{Ra}.\lambda_{Pb} - I_{Pb}.\lambda_{Pb} - \frac{(I_{Pb2}-I_{Pb1})}{t} \qquad \textbf{Eqn. 4.4.1.a.}$$

$$F_S = \frac{V.C_{Po}}{A} + C_{Po}.R + I_{Pb}.\lambda_{Po} - I_{Po}.\lambda_{Po} - \frac{(I_{Po2}-I_{Po1})}{t} \qquad \textbf{Eqn. 4.4.1.b.}$$

where F is the scavenging rate in Bq m^{-2} d^{-1}, I is the inventory of the nuclide in Bq m^{-2}, C is the concentration of the nuclide in Bq m^{-3}, A is the surface area of the loch in m^2, V is the total freshwater flow for the time period in m^3, R is the total rainfall for the time period in m, λ is the decay constant in days^{-1} and t is the length of the time period in days. The scavenging rates calculated in **Eqns. 4.4.1.** are incorporated into the equations describing particulate ^{210}Pb and ^{210}Po in the surface box:

settling = river + scavenging + support - decay - change in storage

$$S_S = \frac{V.C_{Pb}}{A} + F_S - I_{Pb}.\lambda_{Pb} - \frac{(I_{Pb2}-I_{Pb1})}{t} \qquad \textbf{Eqn. 4.4.2.a.}$$

$$S_S = \frac{V.C_{Po}}{A} + F_S + I_{Pb}.\lambda_{Po} - I_{Po1}.\lambda_{Po} - \frac{(I_{Po2}-I_{Po1})}{t} \qquad \textbf{Eqn. 4.4.2.b.}$$

where S is the settling rate in Bq m^{-2} d^{-1}. There is no support term for ^{210}Pb as it is assumed that there is no particulate ^{226}Ra in the waters of Loch Etive.

In the intermediate and deep boxes there are no river or rain inputs. The equations describing dissolved ^{210}Pb and ^{210}Po in these boxes are simple:

scavenging = support - decay - change in storage

$$F_m = I_{Ra}.\lambda_{Pb} - I_{Pb}.\lambda_{Pb} - \frac{(I_{Pb_2}-I_{Pb_1})}{t} \qquad \textbf{Eqn. 4.4.3.a.}$$

$$F_m = I_{Pb}.\lambda_{Po} - I_{Po}.\lambda_{Po} - \frac{(I_{Po_2}-I_{Po_1})}{t} \qquad \textbf{Eqn. 4.4.3.b.}$$

The settling rate from the box above is incorporated into the equations describing particulate ^{210}Pb and ^{210}Po in these boxes:

settling = settling + scavenging + support - decay - change in storage

$$S_m = S_s + F_s - I_{Pb}.\lambda_{Pb} - \frac{(I_{Pb_2}-I_{Pb_1})}{t} \qquad \textbf{Eqn. 4.4.4.a.}$$

$$S_m = S_s + F_s + I_{Pb}.\lambda_{Po} - I_{Po_1}.\lambda_{Po} - \frac{(I_{Po_2}-I_{Po_1})}{t} \qquad \textbf{Eqn. 4.4.4.b.}$$

The calculated scavenging and settling rates in each box are tabulated in **Table 4.4.1.** The largest source of error in the calculation was derived from the rain and river ^{210}Pb and ^{210}Po fluxes since the activity of the nuclides was not determined each month. Instead the average activity of each was used in the calculation. During periods of high rainfall (and hence river flow) the activity of the nuclides will be diluted. Thus there is an over-estimation of the nuclide inputs during these months, which causes considerable error in the surface scavenging and settling results and propagates through all the settling results. The intermediate and deep scavenging rates are more reliable.

In an attempt to estimate a more accurate ^{210}Pb and ^{210}Po flux, total freshwater flow was plotted against river ^{210}Pb and ^{210}Po specific activity. There is no obvious relationship between flow and radionuclide concentration, although this may be due to the limited number of samples and the large activities in the Dec. '91 River Etive sample (see **4.2.**). At low flow rates an increase in flow results in an increase in concentration, but any further increase in flow results in a decrease in concentration due to dilution. The complexity of any mechanism, and the limited number of samples, makes fitting a polynomial expression through the data uncertain; thus I have not corrected the ^{210}Pb and ^{210}Po fluxes used in the model.

Table 4.4.1. ^{210}Pb and ^{210}Po scavenging (*F*) and settling (*S*) rates in the surface (0-10 m), intermediate (10-60 m) and deep (60-120 m) boxes of the Loch Etive water column calculated by a mass balance box-model.

	Scavenging or settling rates (Bq cm^{-2} d^{-1})					
^{210}Pb	*F*s	*S*s	*F*m	*S*m	*F*d	*S*d
20.12.90	12.7	15.1	- 0.11	14.8	0.09	14.6
06.02.91	49.5	59.5	0.62	59.8	0.54	59.9
24.03.91	24.9	29.5	0.17	29.4	0.10	29.3
23.04.91	28.6	34.5	0.47	34.4	0.75	34.2
22.05.91	4.8	5.7	0.26	5.7	0.32	5.9
18.06.91	8.9	10.2	0.20	10.4	0.26	10.3
17.07.91	13.5	15.5	0.33	15.5	0.40	15.6
12.09.91	15.4	17.7	0.26	17.7	0.41	17.6
13.10.91	36.3	43.1	0.40	43.0	0.38	43.0
14.11.91	29.6	34.6	0.23	34.6	0.28	34.5
^{210}Po	*F*s	*S*s	*F*m	*S*m	*F*d	*S*d
20.12.90	25.8	9.1	- 0.94	9.9	- 1.43	10.1
06.02.91	101.6	41.9	0.41	44.4	- 0.57	46.2
24.03.91	50.5	19.0	- 2.34	17.8	- 3.55	17.6
23.04.91	58.1	23.1	- 0.16	22.6	- 1.43	22.5
22.05.91	9.5	3.3	- 0.79	2.7	- 3.48	3.4
18.06.91	17.4	5.0	- 0.64	4.9	- 6.98	4.7
17.07.91	26.6	8.0	- 0.80	7.7	- 0.34	7.7
12.09.91	30.0	9.4	- 1.41	8.0	- 1.07	7.4
13.10.91	74.1	28.2	0.82	28.0	0.23	28.1
14.11.91	59.6	20.0	0.03	20.6	- 0.05	20.9
12.12.91	43.4	17.3	- 0.44	17.4	- 0.39	17.8
24.02.92	165.9	65.6	- 0.90	66.9	- 3.38	68.3
24.04.92	126.4	45.7	- 1.57	44.8	- 1.49	45.1
20.06.92	49.3	19.2	- 1.00	18.3	- 8.45	18.8

The scavenging rates in the surface box are large and positive, for both ^{210}Pb (range: 4.8 to 49.5; mean and standard deviation: 22.4 ± 13.9 Bq m^{-2}, n=10) and ^{210}Po (9.5 to 165.9; 59.9 ± 44.4 Bq m^{-2}, n=14). These scavenging rates represent the removal of variable and large monthly river and rain inputs. In the intermediate and deep boxes, however, the scavenging rates are small, as there are no large radionuclide inputs. The ^{210}Pb scavenging rate is small and positive in the intermediate (-0.11 to 0.62; 0.28 ± 44.4 Bq m^{-2}) and deep boxes (0.09 to 0.75; 0.35 ± 0.20 Bq m^{-2}) except for the December '90 intermediate box where there is regeneration of ^{210}Pb. There is a negative ^{210}Po scavenging rate, and hence regeneration of ^{210}Po in most months. The magnitude and frequency of ^{210}Po regeneration increases with depth with 11 negative and 3 positive rates in the intermediate box (-2.34 to 0.82; -0.69 ± 0.81 Bq m^{-2}) and 13 negative and 1 positive rate in the deep box (-8.45 to 0.23; -2.31 ± 2.62 Bq m^{-2}). This would be expected as ^{210}Po is more associated with organic particles than ^{210}Pb

(see **1.3.** and **5.3.**) and progressively more of these particles degrade the further they fall through the water column. The scavenging rates propagate through all the settling rate calculations and consequently all the settling rates for both nuclides are large and positive. There is seasonal variation in the nuclide settling rates, with the smallest values found in the summer months, when the rainfall, and hence radionuclide inputs, are lower.

4.5. Discussion and summary

In **Fig. 4.3.7.** it was shown that within the upper 10 m of the water column, dissolved ^{210}Pb and particulate ^{210}Po correlated well with run-off (positively) and salinity (negatively), while particulate ^{210}Pb and dissolved ^{210}Po did not. In the following discussion I attempt to explain this, and summarise all the processes that affect the distribution and quantity of ^{210}Pb and ^{210}Po.

• *Dissolved ^{210}Pb*

Assuming that transport of ^{210}Pb over the entrance sill is balanced, the sources of dissolved ^{210}Pb are rivers, direct precipitation and decay from ^{226}Ra. The first two sources correlate positively with run-off, and thus negatively with salinity. However, since Ra is conservative it correlates positively with salinity, which is the opposite to the observed correlation. The magnitude of the different sources must be considered. Using the same assumptions as SHIMMIELD (1993), the top 10 m of the water column will generate ~1 Bq m^{-2} yr^{-1} of supported dissolved ^{210}Pb. This compares with a direct atmospheric input of ~118 Bq m^{-2} yr^{-1} and a riverine input of ~131 Bq m^{-2} yr^{-1}. Since river and rain inputs dominate, dissolved ^{210}Pb correlates with run-off.

Generally, maximum dissolved ^{210}Pb inventories were found in the winter months when river and rainfall inputs were highest. Maximum ^{210}Pb scavenging residence times were found in the intermediate and deep layers in winter, when the particle flux to the traps (**5.1.**) was low.

• *Particulate ^{210}Pb*

The riverine input of particulate ^{210}Pb, which would correlate positively with run-off, is only ~50 Bq m^{-2} yr^{-1}. The main source of particulate ^{210}Pb must be particles scavenging nuclides from the pool of dissolved ^{210}Pb. The particle flux is dependent

on a number of factors (discussed in **5.1.**) however it is not dependent on run-off so there is no correlation. An assumption has been made that there is no rain or supported input of particulate ^{210}Pb. Maximum particulate ^{210}Pb inventories and settling residence times were found in winter and spring months, when inputs were highest and particle fluxes lowest.

• *Particulate ^{210}Po*

The riverine input of particulate ^{210}Po (~203 Bq m^{-2} yr^{-1}) dominates over decay from particulate ^{210}Pb (~10 Bq m^{-2} yr^{-1}). However particulate ^{210}Po can also be produced by scavenging of the dissolved ^{210}Po pool by particles. By conservation of mass this should be ~508 Bq m^{-2} yr^{-1} which should dominate. Clearly applying the mass balance box-model on a yearly basis fails to adequately describe the processes taking place in the surface box.

• *Dissolved ^{210}Po*

The riverine (~299 Bq m^{-2} yr^{-1}), rainfall (~214 Bq m^{-2} yr^{-1}) and supported (~7 Bq m^{-2} yr^{-1}) inputs of dissolved ^{210}Po, would correlate with run-off. There must be a large input of dissolved ^{210}Po from another source which is not in proportion to run-off. Regeneration of dissolved ^{210}Po from decaying biogenic detritus may be this source. Maximum dissolved ^{210}Po residence times throughout the water column are found in May '91; this suggests that regeneration of ^{210}Po does take place in the surface waters.

Regeneration of dissolved ^{210}Po at depth takes place in most months. The magnitude and frequency of regeneration increases with depth. Maximum rates of regeneration are found in March, April and May, so that large inventories of dissolved ^{210}Po build up in these months, and the residence time of dissolved ^{210}Po increases. The deep dissolved ^{210}Po inventory returned to normal by June in both years.

• *General*

The variation in ^{210}Pb and ^{210}Po activity with season has not been determined in such detail in coastal marine environments before. Odd high ^{210}Po and ^{210}Pb concentrations are explained by the fact that interval sampling may not pick up some variations if biogeochemical processes are more rapid than the sampling; indeed many of the residence times are less than one month. The activities found in the waters of Loch Etive are similar in both magnitude and partitioning to other coastal marine areas. The input flux to the loch via river water is as important as that via

rain. Many previous researchers (e.g. OLDFIELD & APPLEBY, 1984) have discounted river water as an important source of ^{210}Pb to water bodies. It is clear that if the catchment area to surface area ratio is high, this is not the case.

• *Rainwater*

The rainwater ^{210}Po and ^{210}Pb concentrations were widely variable, due to variation in source air mass, and frequency and duration of rain storms. There was a seasonal variation in ^{210}Po concentration. As the year progressed the $^{210}Po/^{210}Pb$ ratio fell below unity, then in May and June there was a massive excess of ^{210}Po. This may be due to variation in the surface water of the ocean as the spring bloom progresses. As there were only six rainwater samples the calculated depositional ^{210}Po and ^{210}Pb fluxes (214 ± 230 and 118 ± 40 Bq m^{-2} respectively) may be unrepresentative of the true yearly flux. The ^{210}Pb flux is consistent with the literature, while the ^{210}Po flux is an order of magnitude higher. This could be because the single massive ^{210}Po activity is unrepresentative, or because there are no comparable ^{210}Po fluxes.

• *River water*

The high $^{210}Po/^{210}Pb$ ratio in rain, in turn causes a high $^{210}Po/^{210}Pb$ ratio in river water. The river ^{210}Po and ^{210}Pb activities were widely variable, depending on the frequency and duration of rain storms. The rivers had large dissolved ^{210}Po and ^{210}Pb activities, presumably because the waters are acidic.

Chapter Five: Fluxes as recorded in Loch Etive sediment traps

5.1. Introduction and total mass flux

The total flux of sedimenting particles in coastal marine waters is composed of four separate components. Firstly terrigenous material, both organic debris and inorganic detrital material from mechanical weathering, will be brought into the surface waters via river run-off. The flux will be controlled by the magnitude of river flow. Secondly marine sedimentary material (again a mixture of organic and inorganic material), either from outside the loch or resuspended from the sides of the basin, will be brought into the water column driven by tides. This flux will presumably be proportional to the amplitude of the tides, with large spring tides bringing more material into the loch than smaller neaps. It is possible that extra material will be brought into the deep basin, or resuspended from the slope, during overspill events. Thirdly there is organic material produced in the water column, largely composed of zooplankton fæcal pellets, but also some body parts. This sedimentation should follow the primary production bloom described in **2.3.** Additionally a minor amounts of aeolian fall-out will be deposited onto the surface of the loch via precipitation.

The salt-corrected total dry mass flux is shown in **Fig. 5.1.1.** A large variation in flux was recorded, with a seasonal pattern apparent despite the breaks in sampling. There is a double maxima in flux in late spring/early summer and autumn, with minimum values recorded in mid-summer, and low constant flux observed throughout winter. This explains the observation that the Pb and Po residence times calculated in **4.3.** were longest in the winter. Variation in mass flux, usually on a seasonal basis, is well characterised in all continuous sediment trap deployments, and the more frequent the sampling the more variable the flux (e.g. SMETACEK, 1980; OVERNELL & YOUNG, 1995) since long deployment times average out highly variable fluxes.

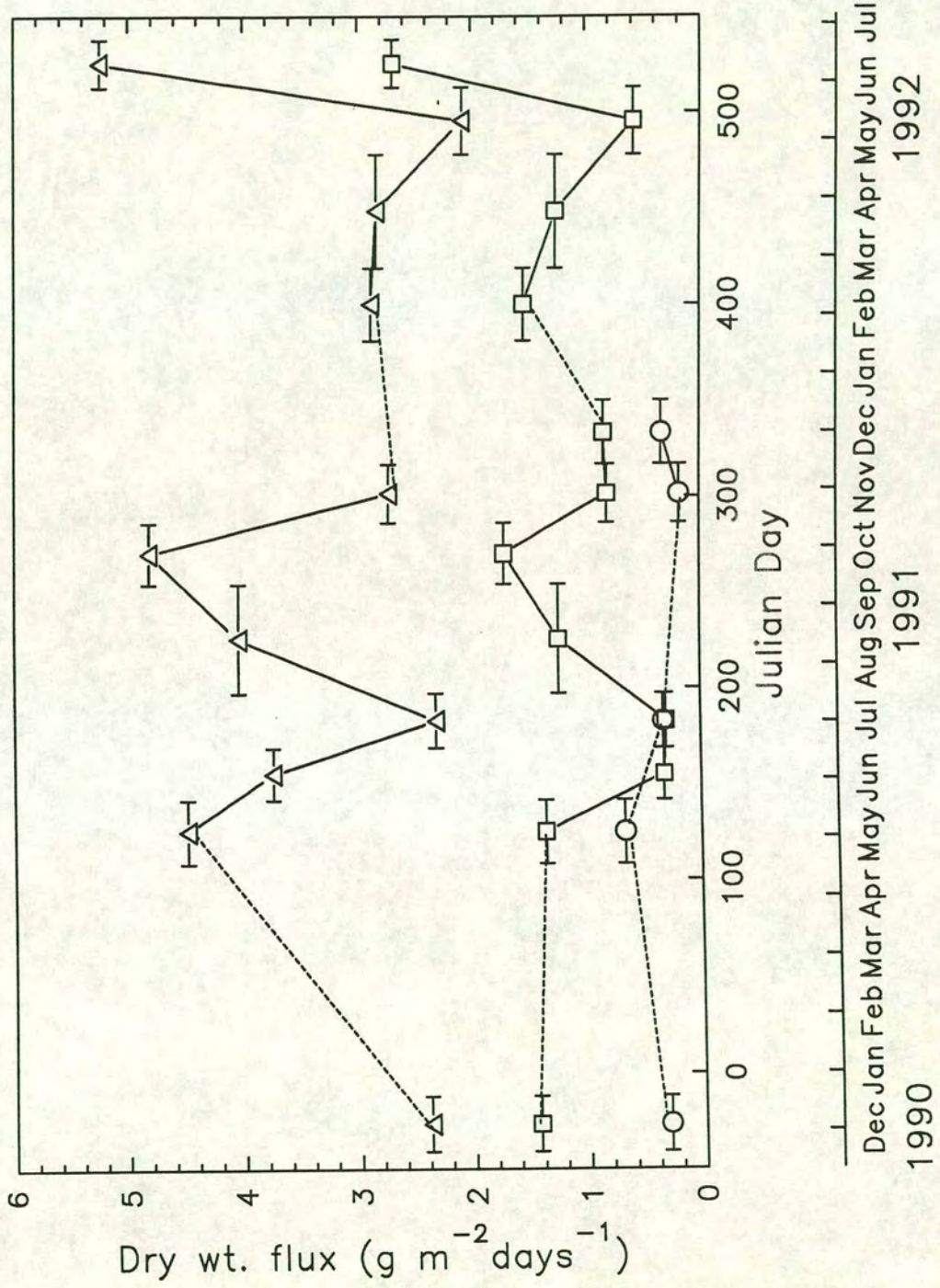


Figure 5.1.1. Total salt-free dry weight flux in Loch Etive shallow ○ , intermediate □ , and deep △ , sediment traps. Dotted lines indicate a sampling hiatus, solid lines continuous deployment. Horizontal error bars represent the deployment period.

Mass flux increases with depth, with the deep trap recording the largest flux each month, and the intermediate trap trapping more than the surface trap in all but the summer months. Again this is a common feature of coastal and fjordic trap deployments and can be attributed to increasing resuspension of sediment with depth. Many studies have shown an increased rate of resuspension and hence sedimentation, in winter months when storms are more frequent (e.g. ANSELL, 1974; SMETACEK, 1980; TSUNOGAI *et al.*, 1986; WASSMAN, 1989). In this study however, highest rates of sedimentation are found in spring and autumn, and this combined with the water depth and stability of the water column suggests that no resuspension from deep sediments takes place - rather there is resuspension from the slope walls into the water column, but at a depth below the 60 m trap.

Table 5.1.1. Comparison of total dry mass fluxes recorded in sediment traps at different locations.

location	**dry mass flux (g m^{-2} d^{-1})** range, (mean, no of samples)	trap position	reference
1. Fjordic environments			
Fanafjorden, W. Norway	1.4 - 4.7, (2.3 ± 0.9, n=10)		WASSMAN, 1984
Framvaren, S. Norway	0.09 - 0.40		NÆS & SKEI, 1988
Saanich Inlet, British Columbia (head of fjord)	0.8 - 3.0 (n=13) 1.5 - 4.1 1.6 - 5.2	50 m 135 m 180 m	SANCETTA & CALVERT, 1988
Saanich Inlet, British Columbia (mouth of fjord)	3 - 8 (n=12) 7 - 14 8 - 22	45 m 115 m 150 m	SANCETTA & CALVERT, 1988
Loch Linnie, W. Scotland	12.4 20.4 31.0 48.5	20 m 60 m 90 m 110 m	OVERNELL & YOUNG, 1995
Loch Etive, W. Scotland	0.18-0.67, (0.23 ± 0.09, n=5) 0.30-2.7, (1.2 ± 0.29, n=12) 2.1 - 5.2, (3.1 ± 1.4, n=11)	shallow trap intermediate trap deep trap	this study
2. Other environments			
Barents Sea	1.34, 1.22		WASSMAN, 1989
Kiel Bight	1.99-5.98 (3.99 ± 2.82, n=2) 2.23-7.34 (4.88 ± 2.56, n=3)	15 m 18 m	SMETACEK, 1980
Funka Bay, Japan	0.79-5.00 (2.75 ± 1.98, n=7) 1.17-7.09 (3.14 ± 2.42, n=7) 1.38-10.9 (6.33 ± 3.48, n=7)	10 m 40 m 80 m	TSUNOGAI *et al.*, 1986
North Pacific, 46°N 162°E	0.065 - 0.31 (0.14 ± 0.11, n=4)		TAGUCHI *et al.*, 1989
California basins	0.072, 0.036, 0.017, 0.015		BRULAND *et al.*, 1981
Sargasso Sea	0.017 - 0.12 (0.044 ± 0.024, n=13)		BACON *et al.*, 1985

The salt-free mass flux recorded in Loch Etive ranged from 0.18-0.67 g m^{-2} d^{-1} for the shallow trap, 0.30-2.7 g m^{-2} d^{-1} for the intermediate trap and 2.1-5.2 g m^{-2} d^{-1} for the deep trap. As shown in **Table 5.1.1.** this is around two orders of magnitude greater than a mid-ocean gyre, around one order of magnitude greater than the productive northern North Pacific Ocean, and of similar magnitude to the highly variable flux in other coastal and fjordic regions. This variability is due to differences in productivity and freshwater input. The position of traps within a fjord also affects the mass flux; traps at the mouth of Saanich Inlet collected more material than traps in its centre, as there was resuspension of material from the entrance sill, and increased productivity in the ocean currents which enter the Inlet (SANCETTA & CALVERT, 1988).

Due to the occasional loss of the traps, there are gaps in the sediment trap record, so in order for the yearly flux to the sediment to be calculated, the flux within these gaps has been estimated by interpolation. The gap between the first and second deployment was considered too long for accurate estimation of flux, so the yearly flux has been estimated from the period 19th April 1991 to 22nd June 1992. As an estimation of the inaccuracy of this, the percentage of the time period that had to be estimated will be given in this and future sections. For the total mass flux the estimation necessary was surface trap, 48%; intermediate trap 8%; deep trap 15%. The yearly fluxes were 127 g m^{-2} yr^{-1} for the surface trap, 423 g m^{-2} yr^{-1} for the intermediate trap and 1226 g m^{-2} yr^{-1} for the deep trap.

In an attempt to determine the importance of each of the separate components of the total mass flux, I have correlated it against various parameters. The total run-off over the deployment period plus the week before, has been plotted against mass flux in **Fig. 5.1.2.** The correlation in the deep and intermediate traps is very weak, although the correlation progressively weakens with depth which would be expected. There is a better negative correlation in the shallow traps, although with only five samples the significance is poor. The lack of a correlation is surprising as given Loch Etive's large catchment area and high run-off, a run-off dominated mechanism might be expected. Certainly the position of the traps is a factor, in traps stationed in 20m of water at the head of Loch Etive, ANSELL (1974) found a strong correlation between run-off and sedimentation. Presumably most of the riverine suspended load is lost soon after entering Loch Etive when current speeds drop, and not carried to the deeper parts of the loch. WILLIAMS *et al.*, (1987) found dilution of surface sediment by terrestrial material only in two transect samples adjacent to the outlets of rivers.

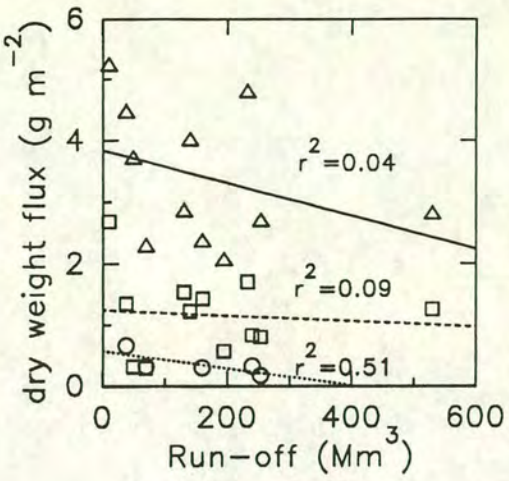


Figure 5.1.2. Correlation of mass flux in shallow ○ , intermediate ❑ , and deep △ , sediment traps with run-off in the deployment period and the preceding week.

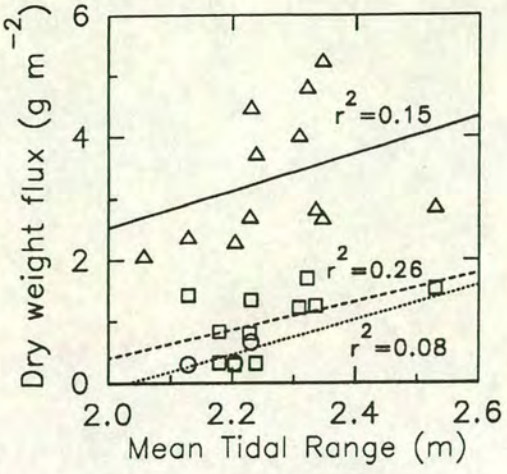


Figure 5.1.3. Correlation of mass flux in shallow ○ , intermediate ❑ , and deep △ , traps with mean tidal amplitude.

Fig. 5.1.3. shows the correlation of mass flux with mean tidal amplitude over the trap deployment period. Sediment traps deployed in Loch Linnie and sampled on a frequency of days have shown a good correlation of mass flux with tidal amplitude (OVERNELL & YOUNG, 1995), although this is a more tidally active system than Loch Etive. Here there is a weak correlation between deployment period mean tidal amplitude and the mass flux in the intermediate trap, with insignificant correlation at the other depths. This suggests that any sedimentary material brought into the deep basin of the loch by tidal forces is introduced to the intermediate waters (10-60 m). It is possible that any variation in mass flux caused by tidal range is averaged out by the long sampling periods in this study.

One might assume that the mass flux is related to the primary production bloom, as the maximum values are found in summer, with a double peak in summer '91. However the C_{org} and C/N results which I shall discuss in **5.2.** show that this is not the case, as the summer samples have a similar composition as the winter samples.

All three peaks in mass flux can be attributed to overspill events. It was shown in **3.2.** that 8% of the bottom water was replaced by dense sill overflowing water in September 1991. This resuspended sediment from the slope and brought it into the deep basin. In addition the low rainfall in May '91, and June '92 might have been expected to cause further renewal but no evidence could be found in the temperature and salinity data to confirm this.

The presence of excess sediment in these month's sediment trap samples suggests that overflows did take place in these months, but only to mid-depths. This would have introduced sediment to the mid water column, and hence the traps.

5.2. Major and minor element geochemistry

Organic Carbon and Nitrogen

The results for C_{org} conc., C_{org} flux, and C/N ratio are shown in **Fig. 5.2.1.** and tabulated in Appendices **B5.1.-3.** Most samples have a similar C_{org} concentration of around 10 wt.%, while surface and intermediate samples in May and June 1991 have elevated concentrations reaching 31%. This pattern was previously observed by ANSELL (1974) in sediment traps positioned in the outer basin of Loch Etive in Aird's Bay: broadly similar C_{org} concentrations of 5-12 wt.% in most samples with a single spring sample over 30 wt.%. There is little variation in the deep trap C_{org} concentration, which is usually less than that in the intermediate trap, indicating dilution of source material with resuspended sediment. Average C_{org} concentrations are surface trap 13.4; intermediate trap 10.6; deep trap 8.6. The average sediment core C_{org} concentration is 5.6 wt.% indicating some post-depositional degradation of organic matter.

ANSELL (1974) deployed sediment traps in Loch Etive continuously for a year in Aird's Bay and at the head of Loch Etive, to measure the fluxes of organic detrius to the sediment. He reported C_{org} fluxes, C_{org} and N concentrations, and C/N, C/chlorophyll and chlorophyll/total pigment ratios. The head of the loch is highly affected by terrestrial material carried by the River Etive, with the highest sedimentation rates found during autumn and early winter, when the flow rates of the river were greatest. There was a clear correlation between the rate of flow and the sedimentation rate at the 12 and 18 m depths, but at 6 m the sedimentation rate was enhanced during the summer by primary production. In Aird's Bay however the sedimenting material was "more directly the result of resuspension of bottom material, much of it probably from the shallower areas around the sides of the loch". Here, winter Carbon fluxes were three times those in summer.

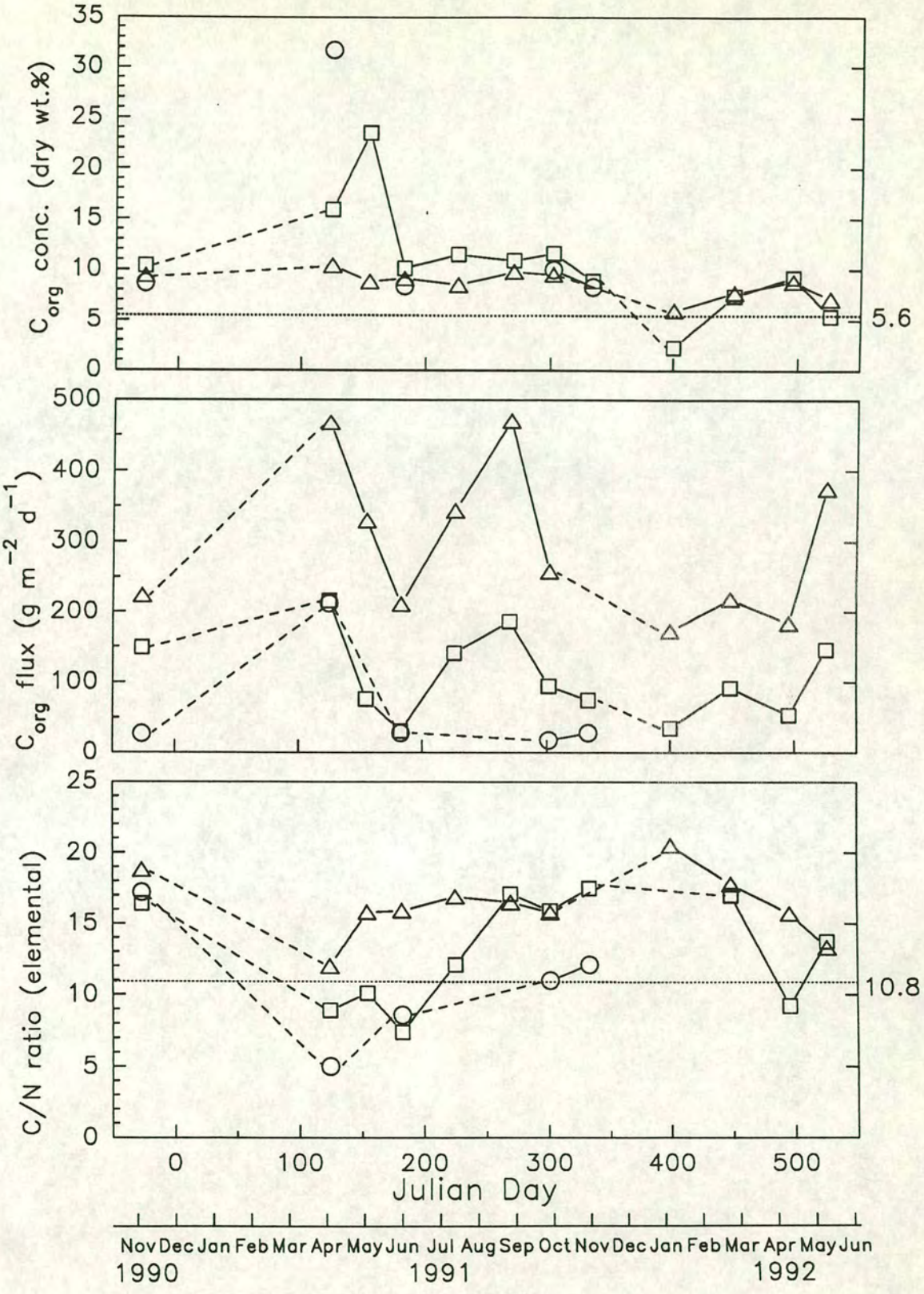


Figure 5.2.1. Organic carbon concentration (top), flux (middle), and elemental C/N (bottom) ratio in Loch Etive shallow ○ , intermediate □ , and deep △ , sediment traps. Solid and dashed lines as **Fig. 5.1.1.** Dotted line indicates the average deep station surficial (0-10cm) sediment concentration, which is also printed on the right of the graph. Deployment period horizontal error bars, which would be the same as **Fig 5.1.1.** have been omitted for clarity.

Table 5.2.1. Comparison of Carbon fluxes recorded in sediment traps at different locations.

location	**Carbon flux (mg C m^{-2} d^{-1})** range, (mean, std. deviation)	trap position	reference
1. Fjordic environments			
Loch Etive, W. Scotland (deep station)	17.7 - 212, (62.4 ± 74.8, n=5) 30.7 - 216, (108 ± 56.9, n=12) 172 - 470, (295 ± 103, n=11)	shallow trap intermediate trap deep trap	this study
Loch Etive, W. Scotland (Aird's Bay)	1.4 - 70 (n = 8) 8 - 60 (24.6, n = 11) 13 - 684 (238, n = 16) 180-700 (n = 7)	9 m 18 m 36 m 54 m	ANSELL, 1974
Loch Etive, W. Scotland (head of loch)	8 - 1000 (n = 22) 7 - 3500 (n = 24) 4.5 - 6000 (n = 25)	6 m 12 m 18 m	ANSELL, 1974
Loch Creran, W. Scotland	12 - 600 (n = 19) 11 - 5000 (n = 22) 18 - 4000 (n = 21) 32 - 900 (n = 19)	9 m 18 m 27 m 36 m	ANSELL, 1974
Framvaren, S. Norway	10 - 120		NÆS & SKEI, 1988
Saanich Inlet, British Columbia (head of fjord)	80 - 320 (n=13) 100 - 300 100 - 500	50 m 135 m 180 m	SANCETTA & CALVERT, 1988
Saanich Inlet, British Columbia (mouth of fjord)	160 - 440 (n=12) 260 - 800 280 - 600	45 m 115 m 150 m	SANCETTA & CALVERT, 1988
Fanafjorden, W. Norway	90 - 590, (252 ± 138, n=11) 150 - 510, (282 ± 118, n=11)	60 m 90 m	WASSMAN, 1984
2. Other environments			
Barents Sea	250 ± 75, 109 ± 30.5		WASSMAN, 1989
Kiel Bight	112-241 (177 ± 91, n=2) 123-299 (238 ± 100, n=3)	15 m 18 m	SMETACEK, 1980
Otsuchi Bay, NE Japan	80 - 230 (153 ± 75, n=3) 200 - 270 (227 ± 38, n=3) 70 - 150 (123 ± 46, n=3) 50 - 100 (77 ± 25, n=3) 60 - 120 (88 ± 32, n=4)	35 m 50 m 60 m 70 m 75 m	KOJIMA & OHTA, 1989

The total yearly C_{org} flux was estimated as above, by estimating the gaps in the record. Since C_{org} was determined in every sample, the amount of estimation needed was the same as for the total mass flux (**5.1.**). The fluxes were 22 g m^{-2} yr^{-1} for the surface trap, 37 g m^{-2} yr^{-1} for the intermediate trap and 104 g m^{-2} yr^{-1} for the deep trap. In the deepest traps of ANSELL (1974) a larger C_{org} flux was found in Aird's Bay of 247 g m^{-2} yr^{-1}, but a lower flux at the head of the loch of 82 g m^{-2} yr^{-1}. The amount of resuspension must be considerably higher in Aird's Bay, which is a shallower, more dynamic environment.

WOOD *et al.* (1973) estimated the net C production, by an in-situ incubation ^{14}C uptake method, in the euphotic zone of Aird's Bay to be 70 g m^{-2} yr^{-1}. The lower primary production in the inner basin may be nutrient limited.

N concentration decreased and became less variable with depth. Mean N concentration was 2.2 ± 2.9 wt.% in the surface trap, 1.05 ± 0.75 wt.% in the intermediate trap and 0.64 ± 0.16 wt.% in the deep trap. The average surficial sediment concentration was 0.44 wt.%. ANSELL (1974) reported very similar results in Aird's Bay; N concentrations varied around 1 wt.% all year, except for a peak greater than 6 wt.% in May. The traps at the head of the loch produced a different picture, with N concentrations 1-3 wt.% all summer and <0.5 wt.% in winter. The yearly N flux was estimated in the same manner as the yearly C flux, with the same amount of estimation, to be 4.3 g m^{-2} yr^{-1} for the surface trap, 3.3 g m^{-2} yr^{-1} for the intermediate trap and 7.7 g m^{-2} yr^{-1} for the deep trap.

The elemental C/N ratio shows seasonal behaviour, with high values (16-20) in winter, intermediate values (9-17) in summer and autumn, and low values in spring reaching 5. Month to month variations were small, with smooth trends visible at all depths. There is an increase in C/N ratio with depth. The C/N ratio determined in Aird's Bay traps by ANSELL (1974) had a wider range, from 1 to 21, and the month to month variablity was considerable. At the head of the loch he reported similar month to month variablity, while the C/N ratios were considerably higher, usually 10-20, with two samples >30. This difference in variability may be due to analytical improvements in the last 20 years, but it could be a reflection of the greater stability of the water column in the deep basin.

The C_{org} and C/N results rule out primary production as the main source of the maximums in mass flux discussed in **5.1.** Three months have peaks in mass flux in the deep traps: Apr. '91, Sept. '91, and June '92. However in all three the C_{org} concentration is similar to that found in winter. The Apr. '91 surface trap is 32 % C_{org} by weight, and the May '92 intermediate trap is 24 % C_{org}, but this organic material appears to be recycled before it reaches the deep trap where the only evidence of a plankton bloom is an increase of 1.5 wt.% above background in Apr. '91.

The C/N ratio is far more sensitive to input from primary production than C_{org} wt.% and this will be considered to try and separate sources. The deep trap C/N ratio is

consistent all summer and averages 16.1, while in Apr. '91 the C/N ratio in the deep trap is 12.0. Taking the C/N ratio of plankton to be 5.2 (MALCOLM, 1981), and a winter C/N average of 19.0 then a simple mixing curve suggests ~50 % of C_{org} and thus ~5 % of the total mass in the deep Apr. '91 sample is due to primary production. The C/N ratio in the June '92 deep trap was lowered by a smaller amount. The C/N ratio is 13.3, indicating that ~41 % of C_{org} and ~3 % of the total mass of the sample is due to primary production. A similar calculation for the Sept. '91 deep trap suggests primary production accounts for ~18 % of the C_{org} and ~2 % of the total mass. Clearly although the flux of C_{org} is increased in these three months by primary production, the major part of the total mass flux is due to a massive influx of resuspended inorganic material. Also resuspension makes up most of the C_{org} flux, and hence presumably the dry mass flux through the deep trap.

Iron and manganese

The concentration, flux and ratio to Al results for Fe and Mn are shown in **Figs. 5.2.2.** and **5.2.3.** respectively, and tabulated in Appendices **B.5.1.-3.** Both the Fe and Mn fluxes to the sediment increase with depth, indicating horizontal advection, resuspension or a cycling mechanism based on reductive dissolution followed by oxidative precipitation. The Fe concentration of all the samples is broadly similar, ranging from 4 to 6 wt.% in most samples, only lower in samples diluted with organic material, and higher in samples that may well have Fe contamination from the rusting trap frame. Indeed one sample (ST8-20m) with a Fe concentration of 13.8 wt.% has not been plotted in **Fig. 5.1.5.** The Fe/Al ratio also gives evidence for contamination of ST8-20m and ST8-60m with values of 7.14 and 1.76 respectively, while the other samples range from 0.6 to 1.0. The average surface sediment Fe concentration and Fe/Al ratio is 5.4 wt.% and 0.74 respectively, within the trap sample ranges, indicating that the source material undergoes little change with respect to Fe, or that resuspension of whole particles is taking place, rather than precipitation of Fe oxyhydroxides. The yearly Fe flux was estimated as above, but some of the samples contained too little material for analysis and the contaminated samples were not included, so more estimation was required than for the total dry mass flux: shallow trap 74%; intermediate trap 37%; and deep trap 15%. The fluxes were 4.29 g m^{-2} yr^{-1} for the surface trap, 27.4 g m^{-2} yr^{-1} for the intermediate trap and 66.5 g m^{-2} yr^{-1} for the deep trap.

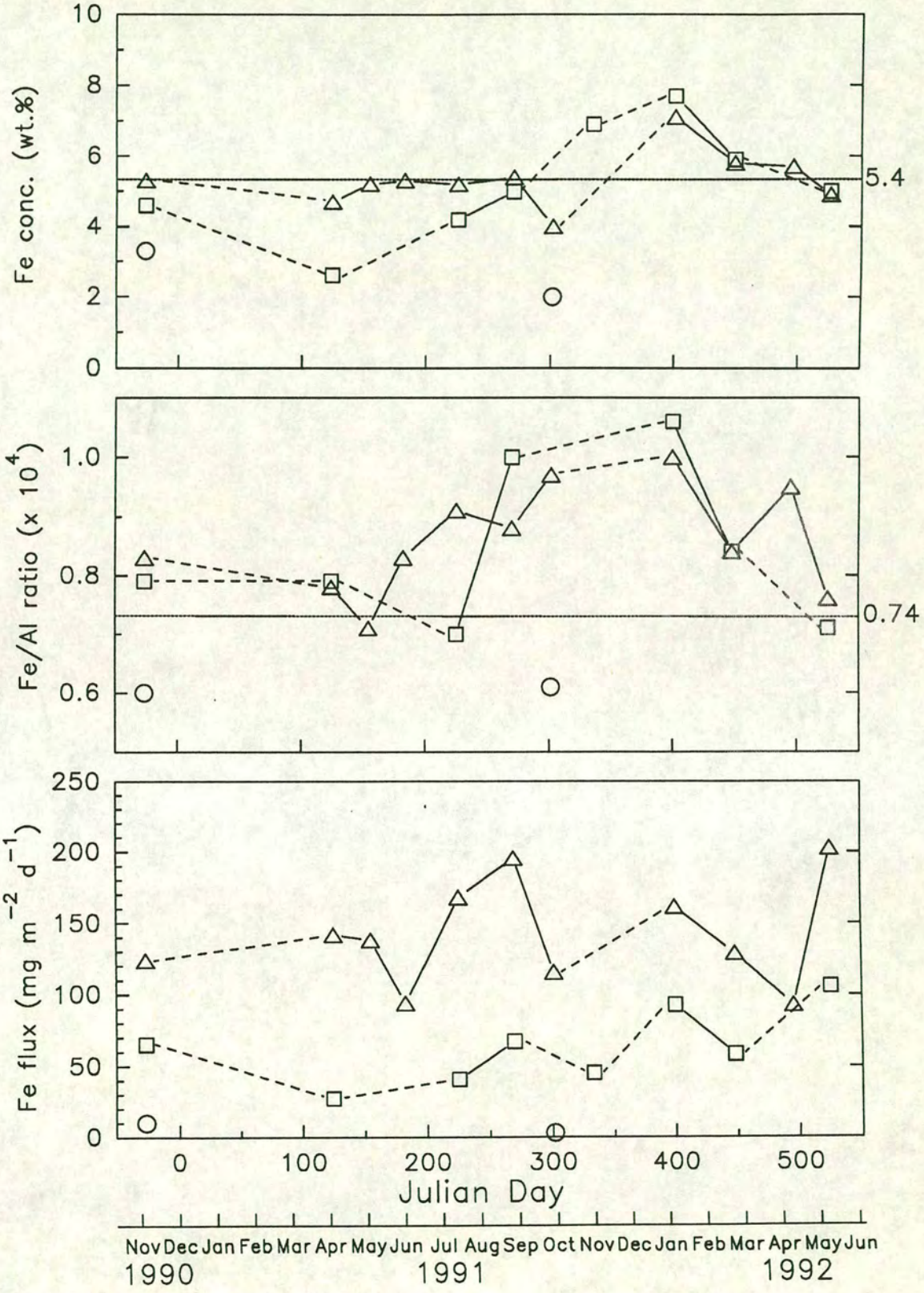


Figure 5.2.2. Iron concentration (top), Fe/Al ratio (middle) and Fe flux (bottom) in Loch Etive shallow ○ , intermediate □ , and deep △ , sediment traps 1990-1992. Solid and dashed lines as **Fig. 5.1.1.** Dotted lines and number annotation as **Fig. 5.2.1.**

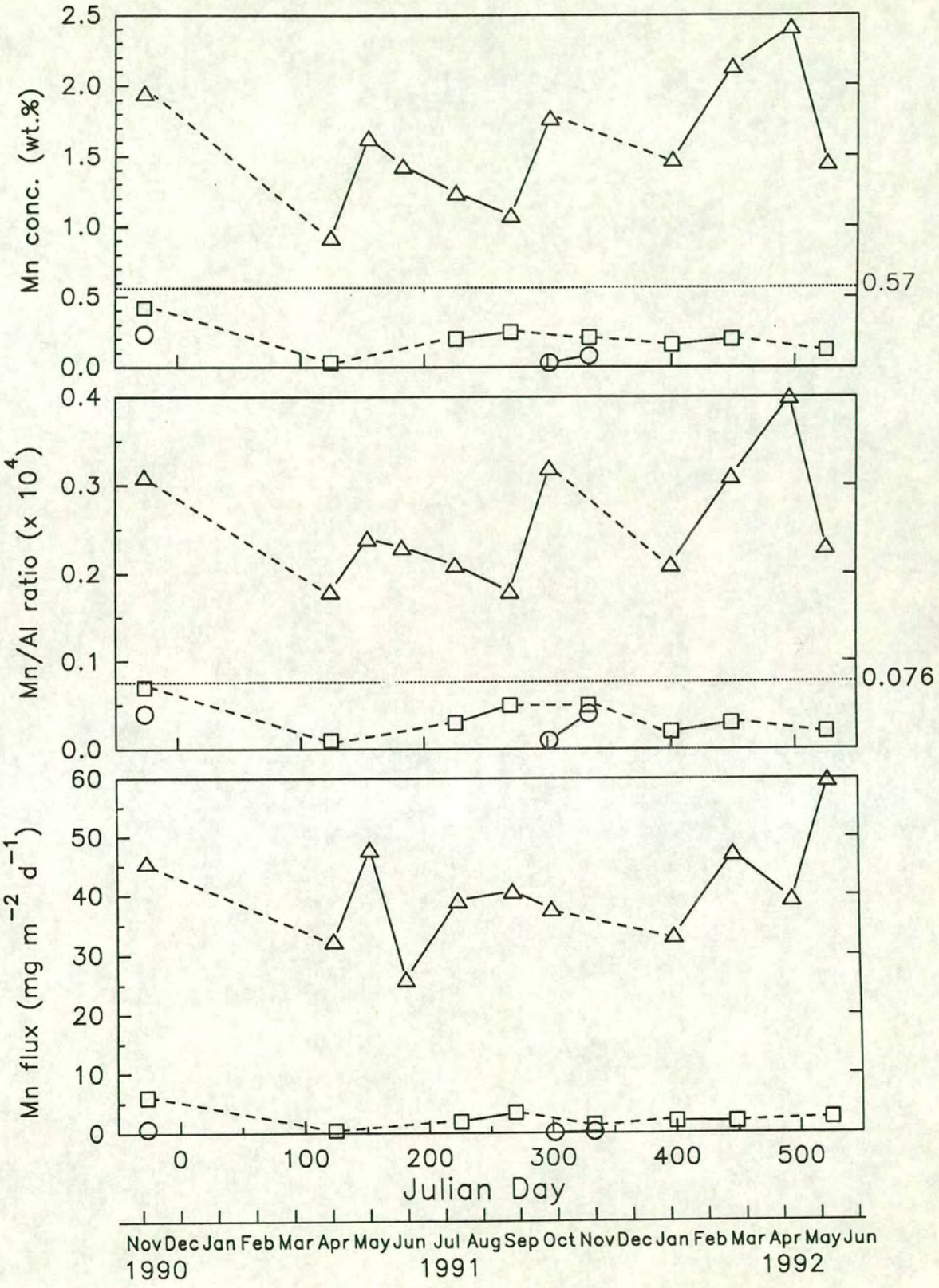


Figure 5.2.3. Manganese concentration (top), Mn/Al ratio (middle) and Mn flux (bottom) in Loch Etive shallow ❍ , intermediate ❑ , and deep Δ , sediment traps 1990-1992. Solid and dashed lines as **Fig. 5.1.1.** Dotted lines and number annotation as **Fig. 5.2.1.**

In contrast the Mn concentration of the deep traps is much greater than that of the intermediate traps. The Mn concentration averages 1.59 wt.% in the deep trap, 0.20 wt.% in the intermediate trap and 0.11 wt.% in the shallow trap. There are four minima in the deep trap Mn concentration data: in May and October 1991, and February and June 1992. The first is due to dilution by organic material from the spring bloom and the others presumably dilution by detrital material low in Mn and C_{org} due to the overspill events. Although the average surface sediment concentration is only 0.57 wt.% at the deep station, in other parts of the deep basin it can reach 5 wt.% (transect core ET 6; WILLIAMS *et al.*, 1987; MALCOLM, 1981). Large Mn concentrations in the deep trap samples are presumably explained by Mn reductive dissolution into the water column followed by precipitation of Mn oxyhydroxides. Resuspension of bottom sediments rich in Mn followed by lateral advection is another possibility. Certainly there is a decoupling of the Mn and Fe cycles; the Fe/Mn ratio decreases dramatically from intermediate to deep trap, approaching unity. The yearly Mn flux was estimated as above, with the same amount of estimation of the record as the Fe flux. The fluxes were 0.117 g m^{-2} yr^{-1} for the surface trap, 0.869 g m^{-2} yr^{-1} for the intermediate trap and 18.4 g m^{-2} yr^{-1} for the deep trap.

5.3. Radionuclides

^{210}Pb

The ^{210}Pb activity in the sediment trap samples was measured by alpha spectroscopy after storage to allow decay of excess ^{210}Po. The ^{210}Po activity was not determined. The ^{210}Pb specific activity, ^{210}Pb/Al ratio and the ^{210}Pb flux results are tabulated in Appendices **B.5.1.-3.** and plotted in **Fig. 5.3.1.** There was temporal variation in the ^{210}Pb specific activity with no apparent pattern. The intermediate and deep traps contained similar activities, while the surface trap contained considerably less in the summer months, suggesting that the new organic matter is low in ^{210}Pb. The deep trap had a larger activity than the intermediate trap in early summer, but in the rest of the year the deep trap had a lower ^{210}Pb activity. The seasonal variation and increase in depth in the ^{210}Pb flux is due to the differences in the mass flux. The mean yearly flux was obtained as above, and since every sample was analysed, the same degree of

estimation as the total dry mass flux was needed. The fluxes were 7.71 Bq m^{-2} yr^{-1} for the shallow trap, 131 Bq m^{-2} yr^{-1} for the intermediate trap, and 398 Bq m^{-2} yr^{-1} for the deep trap.

The ^{210}Pb activity of the surface Apr. '91 sample is very low, indicating that the organic matter that makes up 32 % of this sample is low in ^{210}Pb relative to the other sources of particulate material. The maximum ^{210}Pb activities (5-6 Bq g^{-1}) are found in mid-winter samples, when there is little variation down the water column. Since surface sediment contains only 3-4 Bq g^{-1}, these activities cannot be due to resuspension. The source of these high ^{210}Pb activities must be run-off. The specific ^{210}Pb activity in the sediment traps is plotted against total run-off in the deployment period plus the week prior in **Fig. 5.3.2.** There is a good correlation between run-off and activity in the intermediate and deep traps (r^2 = 0.623 and 0.544 respectively), while the correlation in the surface traps is poorer (r^2 = 0.175). Since the dissolved phase of the river samples contains most ^{210}Pb (**4.2.**), a mechanism whereby dissolved ^{210}Pb is scavenged upon entering the loch can be envisioned. Possibly the flocculates which are formed when fresh and saline water mix (SHOLKOVITZ, 1976) scavenge dissolved ^{210}Pb.

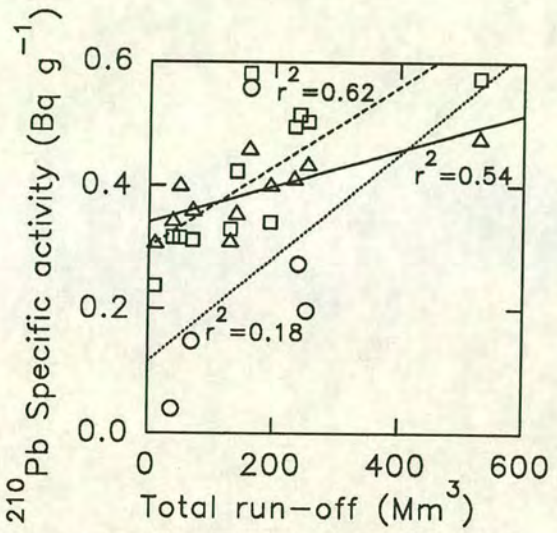


Figure 5.3.2. Correlation of specific ^{210}Pb activity with run-off in the deployment period plus the prior week.

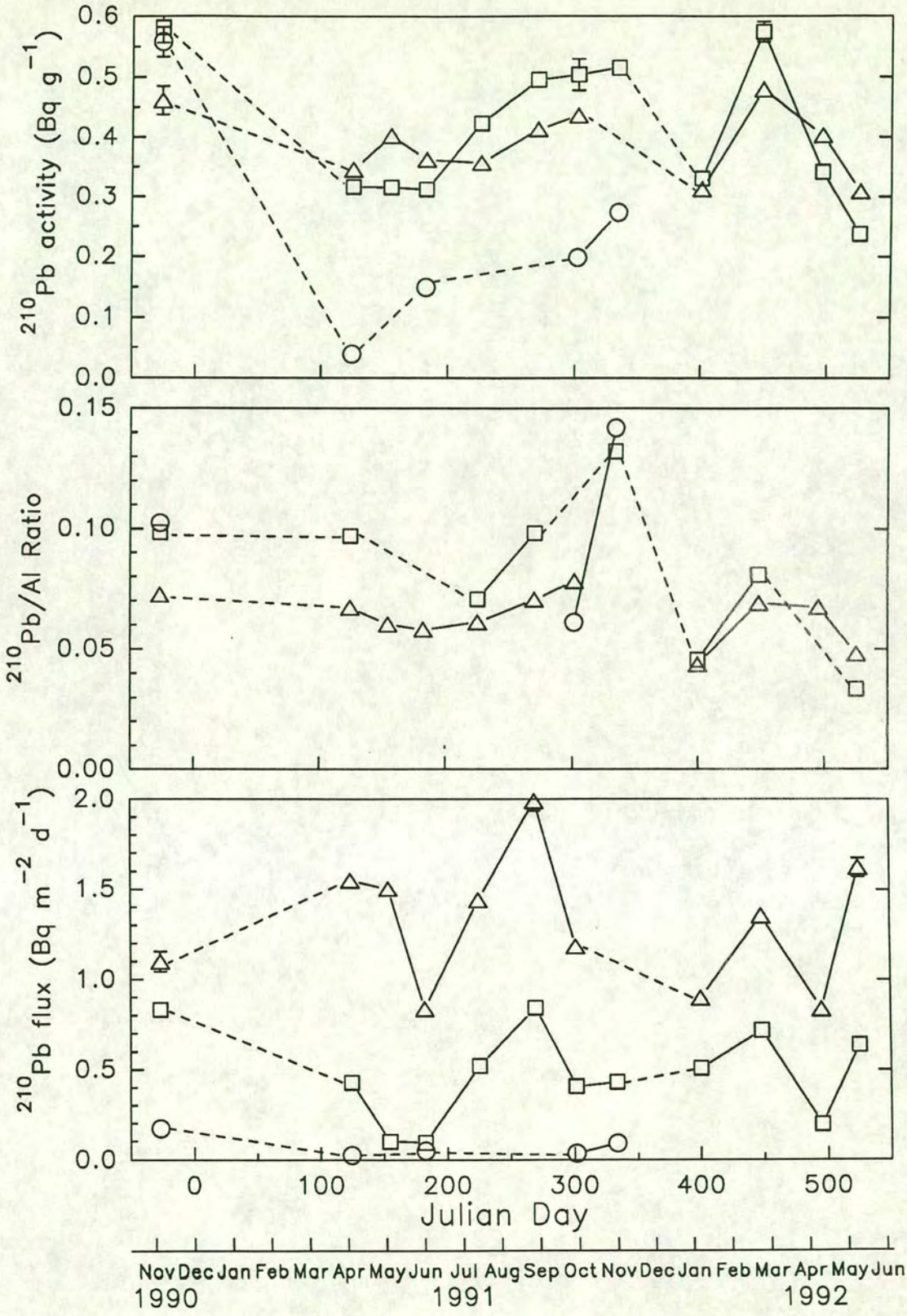


Figure 5.3.1. ^{210}Pb specific activity (top), ^{210}Pb/Al ratio (middle) and ^{210}Pb flux (bottom) in Loch Etive shallow ○, intermediate □, and deep △, sediment traps 1990-1992. Solid and dashed lines as **Fig. 5.1.1.** Dotted lines and number annotation as **Fig. 5.2.1.** Vertical error bars, representing the uncertainty in the ^{210}Pb determination, are shown where bigger than symbol.

In an attempt to determine which components of the particulate flux scavenge ^{210}Pb, sediment trap ^{210}Pb activity was plotted against Mn, Fe, Al and C_{org} concentration, in **Fig. 5.3.3.** The correlation coefficients are tabulated in **Table 5.3.1.** There was no correlation between ^{210}Pb and Fe or C_{org}, but there is clearly a weak correlation between and ^{210}Pb and Al or Mn. The correlation in the surface traps is better than at depth as there are fewer samples here (n=5 for C_{org}, n=3 for Al, Fe, Mn), and hence the significance is poor.

Table 5.3.1. Correlation of ^{210}Pb with various components in Loch Etive sediment traps.

	Al	Fe	Mn	Corg
surface	0.775	0.092	0.989	0.168
intermediate	0.192	0.022	0.323	0.042
deep	0.199	0.006	0.239	0.002

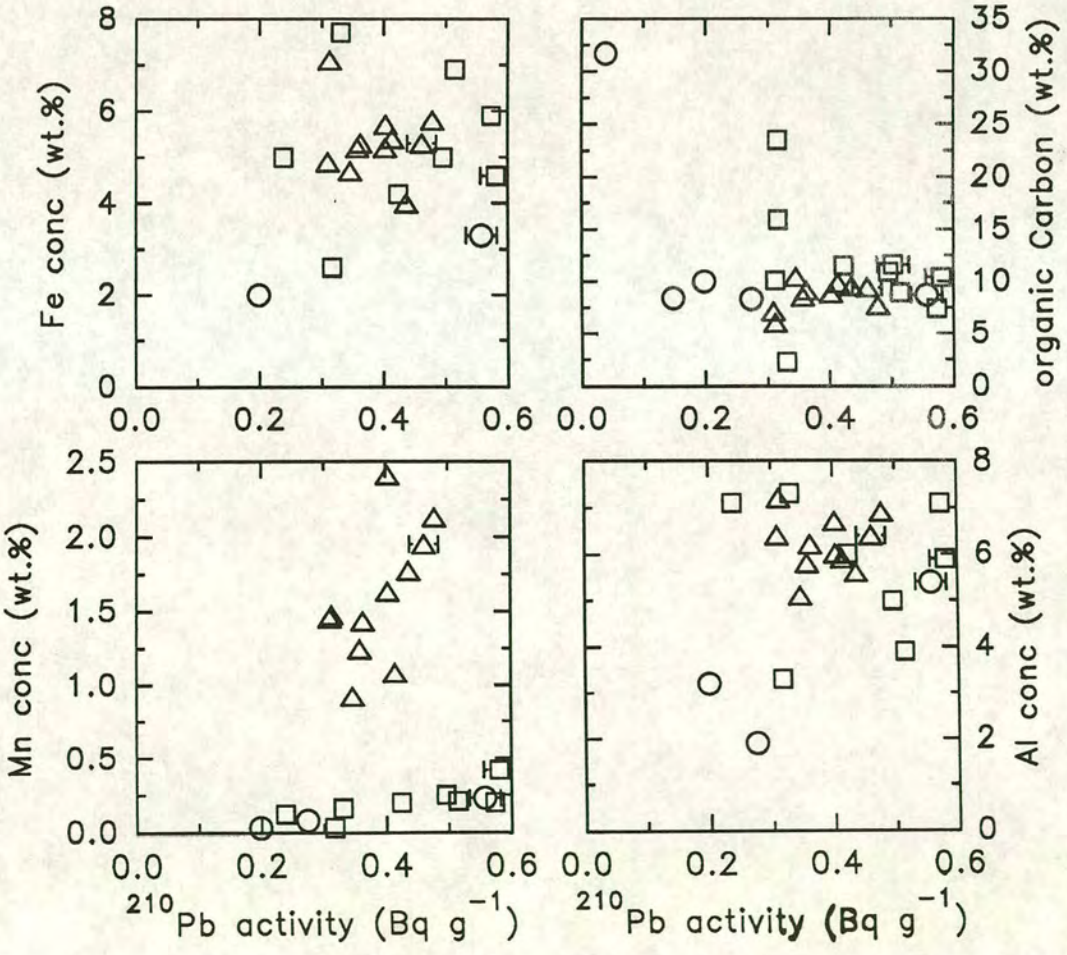


Figure 5.3.3. Correlation of ^{210}Pb with various components in Loch Etive sediment traps.

An association between ^{210}Pb and Mn is to be expected, and an association with Al is explained by clay particles forming flocculates when fresh and saline water mix, which scavenge dissolved ^{210}Pb. However no association with C_{org} is problematic. WILLIAMS *et al.*, (1987) found that ^{210}Pb and C_{org}, covaried in the surface sediment of Loch Etive, although it is possible that they were diluted equally by terrestrial inorganic material. Furthermore, how can ^{210}Pb be diluted by run-off derived inorganics, when run-off is clearly the main source of ^{210}Pb to the sediment traps?

The ^{210}Pb activity in the deep Apr. '91 and June '92 samples is slightly depressed relative to the rest of the deep samples, presumably due to dilution by organic material low in ^{210}Pb. The ^{210}Pb fluxes are mainly controlled by the magnitude of the dry mass flux, except that the low activity in these two samples means their ^{210}Pb fluxes are similar to the other deep samples. Only the Sept. '91 deep sample remains high, indicating that resuspended sediment has a fairly large ^{210}Pb activity.

5.4. Summary

The dry mass and C_{org} fluxes are of similar magnitude to other coastal and fjordic sediment trap deployments. The sedimenting flux increases with depth, indicating resuspension; this is also common in other shallow coastal deployments. However in Aird's Bay (ANSELL, 1974) and many other coastal environments (SMETACEK, 1980; WASSMAN, 1989) maximum dry mass fluxes are found in the winter. This is when storms that mix overlying water and disturb bottom sediments are more frequent. Possibly the stratified water column of the deep basin protects sediments from storm-controlled resuspension. Instead sediment from the shallower areas at the sides of the loch is resuspended and flows down the sides of the basin to depth, especially at times of density inflow over the sill in May and September '91 and June '92. The dry mass flux at the head of the loch (ANSELL, 1974) is also at a maximum in winter, but this is when run-off is most frequent.

Tidal inflow to the deep basin resuspends sediment from the slope twice daily, and it is introduced to the mid-depths of the basin (10-60 m). The amount resuspended is dependent on the height of the tide (and hence the speed of the inflowing water), however the correlation between tidal range and dry mass flux is poor due to the long sampling deployment times which average out the tidal effect.

Rivers bring sediment to the loch in proportion to the rate of flow; sedimentary fluxes are only in proportion to the rate of flow close to the river mouths (ANSELL, 1974). Only a small fraction of the particulates carried by rivers reach the centre of the loch.

Primary production is responsible for a small fraction of the sedimentary flux throughout the summer; it peaks in April '91 and June '92, when it is responsible for a significant proportion of the mass collected by the surface and intermediate traps, but much less of that of the deep trap, which is diluted by resuspension. Primary production is very low in ^{210}Pb, which is surprising, as although plankton concentrate ^{210}Po to a greater extent than ^{210}Pb, it was thought that they did concentrate ^{210}Pb.

To summarise, the dry mass flux is generally low and constant throughout the winter, when important sources include tidal resuspension, river carried material and the aeolian flux. In the summer the addition of plankton debris increases the total flux and the C_{org} concentration and lowers the C/N ratio and ^{210}Pb concentration. These effects reach a maximum in April '91 and Jun. '92 corresponding to the spring bloom. Superimposed on this are three overflow events which resuspended a great deal of sediment which has moderate concentrations of ^{210}Pb and C_{org}.

Dissolved ^{210}Pb is scavenged by both Mn oxyhydroxides and clay flocculates, but not by organic matter or Fe oxyhydroxides. The Fe and Mn cycles are decoupled in the deep trap, presumably due to remobilization of Mn from the deep sediment followed by oxidation and formation of oxyhydroxides. The yearly sedimentary fluxes of the main components are tabulated in **Table 5.4.1.**

Table 5.4.1. Yearly sedimenting fluxes at the deep station, Loch Etive.

	surface trap	**intermediate trap**	**deep trap**
total dry weight	127 g m^{-2} yr^{-1}	423 g m^{-2} yr^{-1}	1226 g m^{-2} yr^{-1}
organic Carbon	22 g m^{-2} yr^{-1}	37 g m^{-2} yr^{-1}	104 g m^{-2} yr^{-1}
Manganese	0.117 g m^{-2} yr^{-1}	0.869 g m^{-2} yr^{-1}	18.4 g m^{-2} yr^{-1}
Iron	4.29 g m^{-2} yr^{-1}	27.4 g m^{-2} yr^{-1}	66.5 g m^{-2} yr^{-1}
^{210}Pb	7.71 Bq m^{-2} yr^{-1}	131 Bq m^{-2} yr^{-1}	398 Bq m^{-2} yr^{-1}

Chapter 6: Loch Etive sediment profiles

6.1. Sediment geochemistry

6.2. Sediment radiochemistry

6.3. Sediment inventories

6.4. Pore water geochemistry and radiochemistry

6.1. Sediment geochemistry

The geochemistry of the transect and long cores was investigated to evaluate changes in sediment types and texture with depth; to characterise the redox properties of the sediment; and to determine fluxes to the sediment of heavy metals. The analysis of 32 elements, was carried out using X-ray fluorescence spectroscopy as detailed in Appendices **A2.4** and **A2.5.** Principal component analysis was carried out to identify groupings among the elements. Major and minor element geochemical analysis of Loch Etive cores has previously been carried out by MALCOLM (1981), RIDGWAY (1984), O'DONNELL (1987) and SHIMMIELD (1993) so only selective interpretation will be carried out. Many long and short cores, and surface grab samples have been taken from Loch Etive by these workers. The notations given to these cores are not consistent, so the sampling locations of the cores are shown in **Fig. 6.1.1.** Each core is preceded by the first letter of the surname of the author. In addition to facilitate easy comparison the transect number of WILLIAMS *et al.* (1987) has been adopted as a standard and is given in parenthesis after every core in discussion.

Major element and porosity results are tabulated in Appendices **Bn.1.**; major elements ratioed to Al are tabulated in Appendices **Bn.2.**; minor element results are tabulated in Appendices **Bn.3.**; minor elements ratioed to Al are tabulated in Appendices **Bn.4.**; where n = 1 for core A, 2 for core B, 3 for core C and 4 for the transect cores. The radionuclide results are tabulated separately in Appendix **B8.1.** (long cores) and **B8.2.** (transect cores).

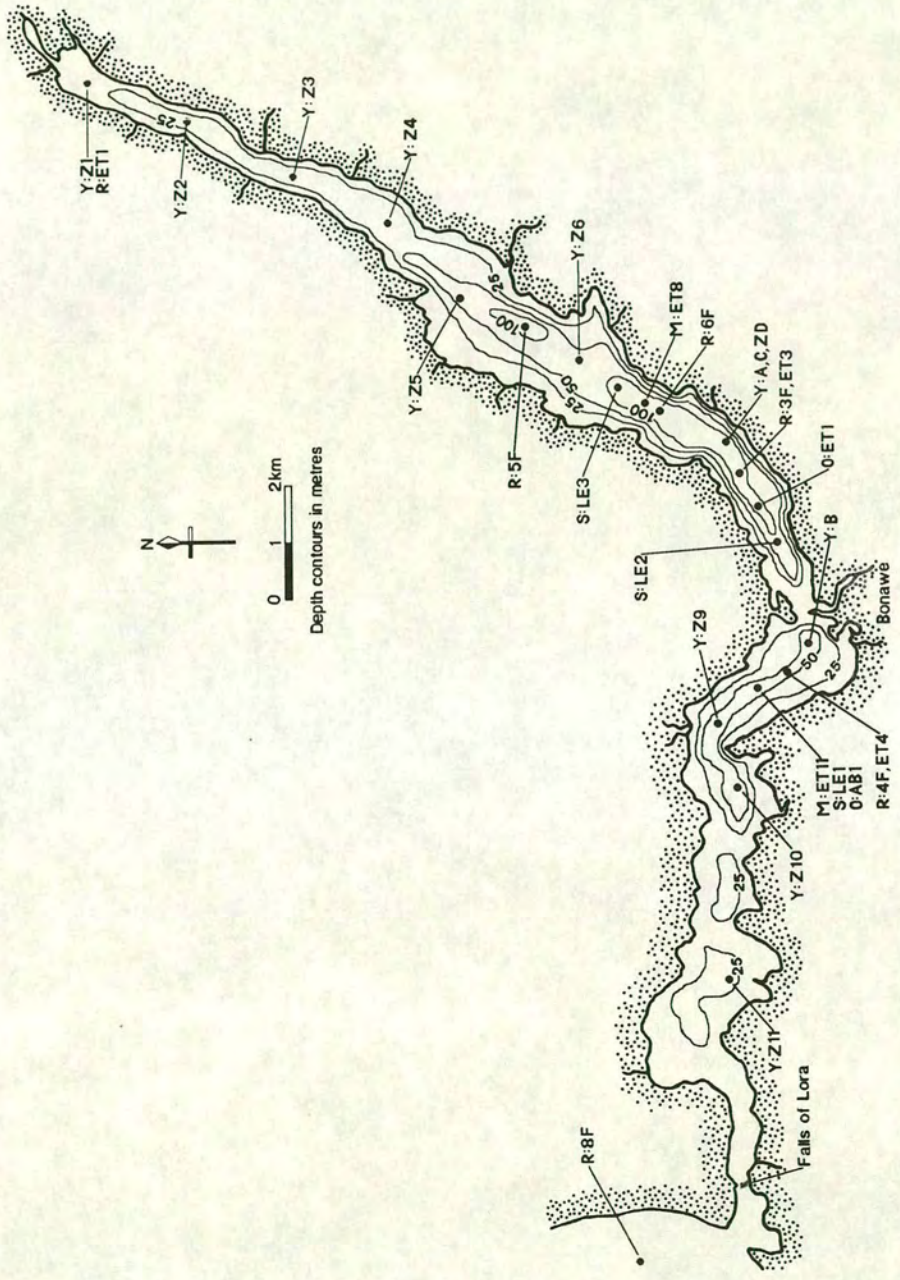


Figure 6.1.1. Location of the long cores taken by MALCOLM (1981), RIDGWAY (1984), O'DONNELL (1987) and SHIMMIELD (1993), and the long and short cores taken for this study. The core notations of each worker are preceded by the letters M, R, O, S and Y respectively.

Porosity

The sediments of Loch Etive, like other organic-rich fjordic basins are exceptionally porous, as shown in **Fig. 6.1.2.** Sediment water content increases towards the deep basin and can reach ~94 % in the deepest part of the loch. The outer basin has more consolidated sediments than the inner basin. Core Z 11 (2) in the seaward, shallow part of the outer basin is much less porous than the rest of the sample set. This core was largely composed of shell debris, compared to the muddy clay of the rest of the cores. The porosity decreases down all the cores due to compaction, although some anomalies are apparent in the long cores. SHIMMIELD (1993) also reports porosity values for her cores: S:LE1 (5) and S:LE3 (14) have similar porositys to the cores from this study, but S:LE2 (10) has a comparatively low porosity, with a surface value of ~88 %. S:LE2 was taken from the steep slope of the deep basin close to the sill at Bonawe, where strong currents are common, leading to winnowing of sediment, affecting the porosity. This also has an effect on the grain size and sedimentation rate of this core.

Grain Size

Grain size was not measured directly, instead the Ti/Al, Zr/Al and K/Rb ratios were studied as geochemical indicators. There is considerable variation in grain size of the sediments of Loch Etive as shown by the Zr/Al ratios in **Fig. 6.1.3.** and the K/Rb ratios in **Fig. 6.1.4.** The Zr/Al ratio decreases from ~31 at the head of the loch to ~15-20 in the deep basin, then climbs again to ~30-35 in the more marine cores. Similarly the K/Rb ratio ranges from ~25 to ~15–20 and back to ~25. The grain size of the deep basin is considerably smaller than at the margins. This is as expected as faster current speeds in the shallower waters, carry fine-grained sediments to the deeper parts of the loch where current speeds drop and the sediment can be deposited. Several authors (MALCOLM, 1981; WILLIAMS *et al.*, 1987) were unable to recover sediment from the sill areas, which were bare and rocky, the high currents having carried away all the sediment. Core S:LE2 (10) (SHIMMIELD, 1993) taken from the slope inside the Bonawe sill has a surface Zr/Al ratio of ~37, even greater than that found in core Y:Z11 (2). The winnowing processes affecting this core must be particularly strong.

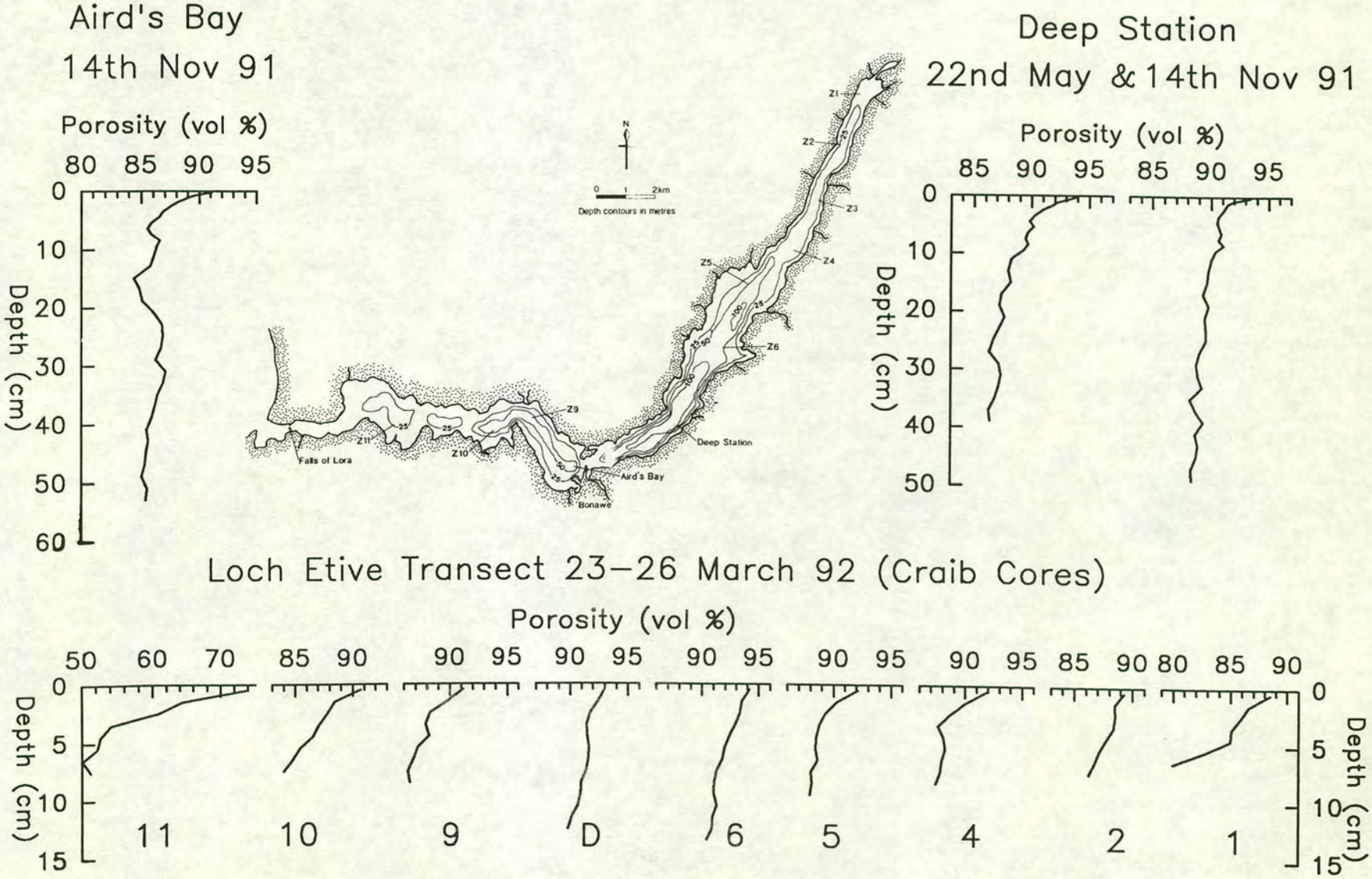


Figure 6.1.2. Porosity of the sediments of Loch Etive, 1991-2.

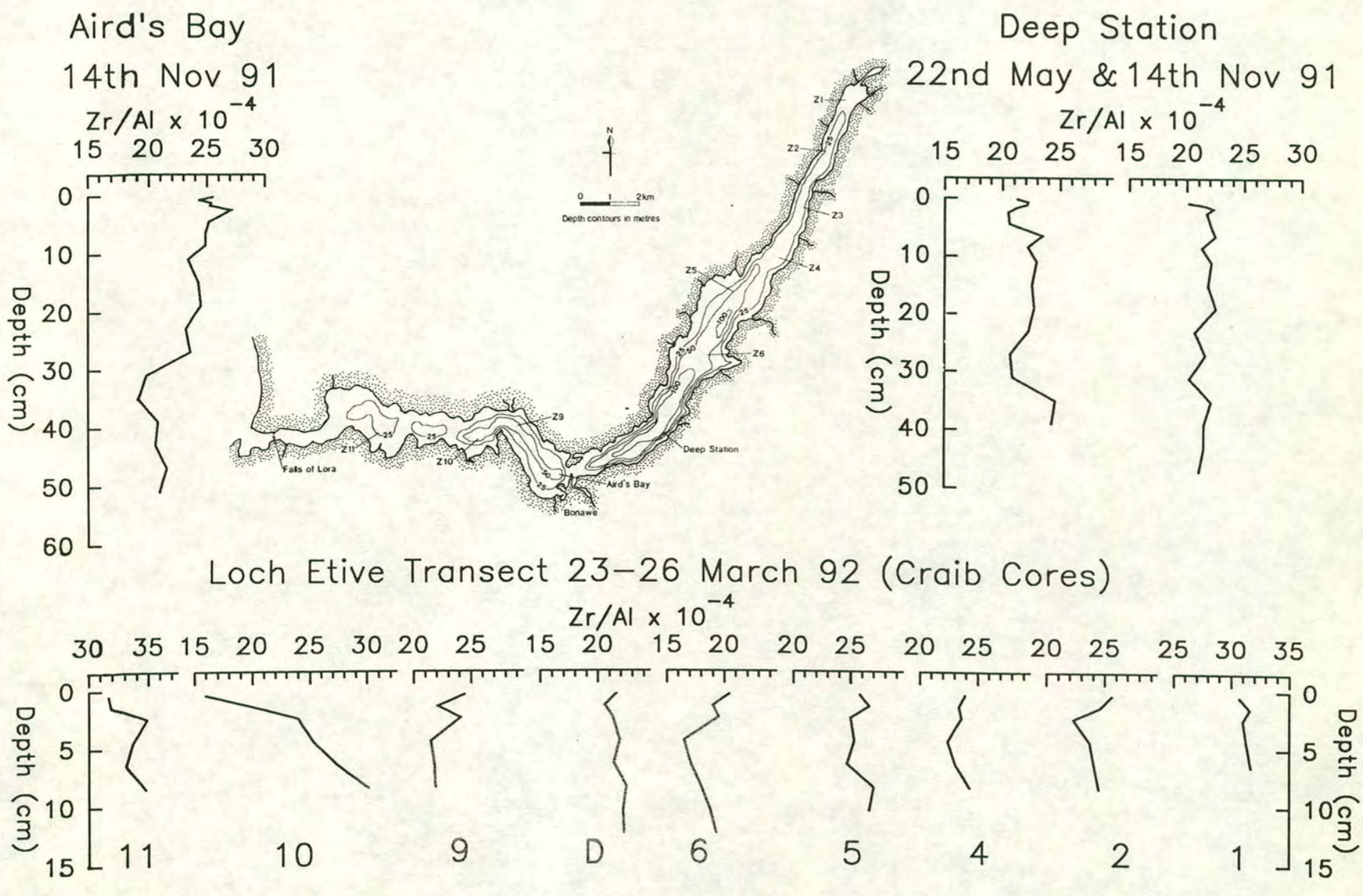


Figure 6.1.3. Zr/Al ratio in the sediments of Loch Etive, 1991-2.

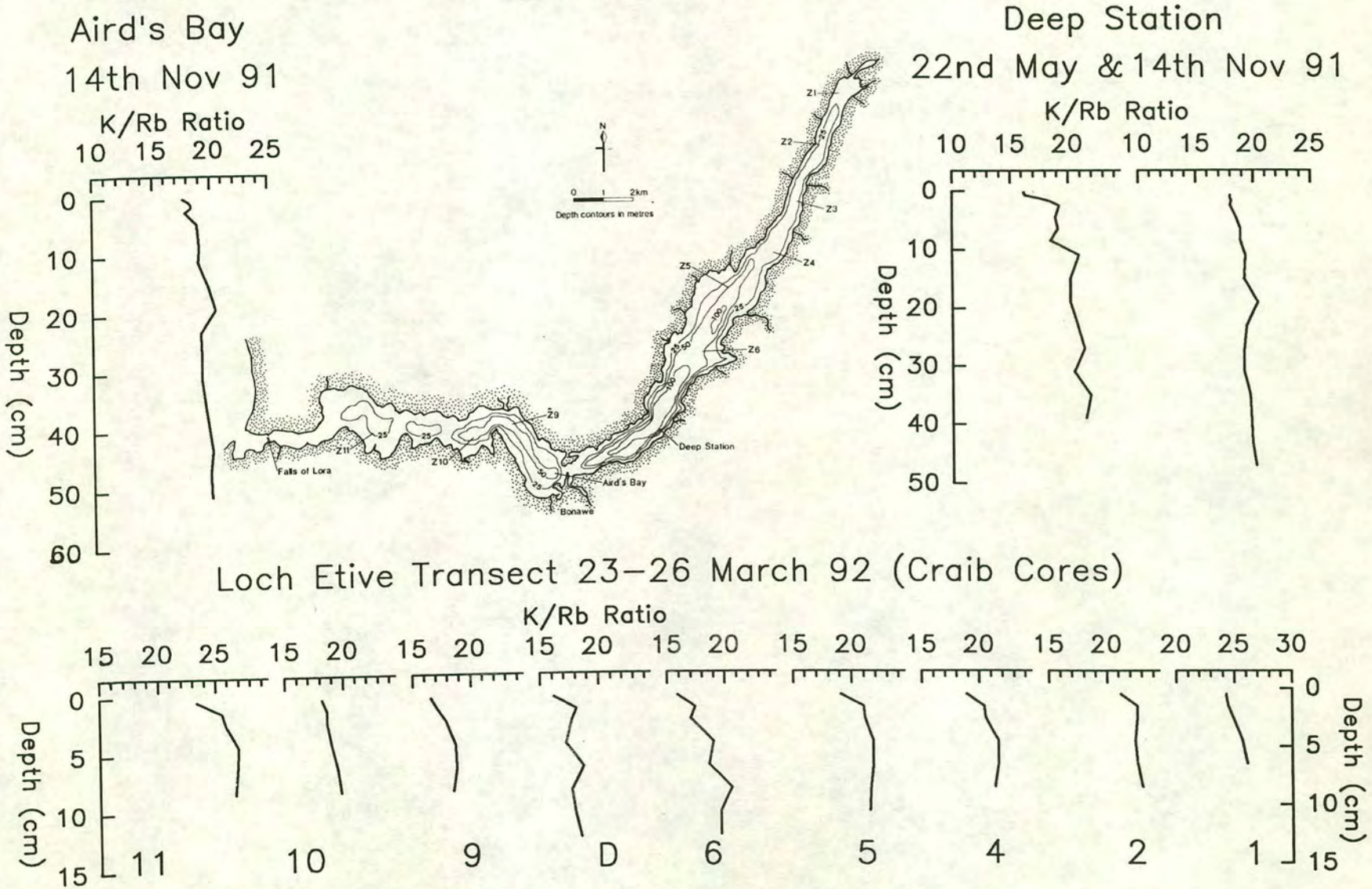


Figure 6.1.4. K/Rb ratio in the sediments of Loch Etive, 1991-2.

Manganese and Iron

WILLIAMS *et al.*, (1987) determined Mn concentrations in the surface sediment along a transect of Loch Etive, reporting a massive Mn enrichment in the deep basin. The Mn profiles from this study's short core transect in **Fig. 6.1.5.** adds detail to the understanding of Mn cycling in Loch Etive. There is a gradual increase in Mn peak concentration and in deep background Mn concentration towards the deep basin. In the deepest part of the Loch (core Y:Z6 (15)) surface Mn concentration is 5.3 wt.%, 100 times greater than that found at either end of the Loch. A possible mechanism to allow such enrichment involves four steps: reductive dissolution of Mn out of the reducing sediments into the oxidising waters; oxidative precipitation of Mn as very fine-grained Mn oxyhydroxides; lateral transport of Mn oxyhydroxides to the deep waters where a reduction in current speed allows the particles to sediment out. An alternative mechanism whereby solid phase Mn in the surface floc and sediment is resuspended and transported by winnowing before being redeposited is also plausible. It is reasonable to assume a mixture of the two mechanisms. Of key importance in both however, is the small grain size of the Mn oxyhydroxides allowing them to be carried great distances before being redeposited, and the location of the Mn peak at the sediment surface; thus large quantities of Mn can easily be introduced to the water column, by either mechanism.

Fe however, shows only a slight enrichment in the sediments of the deep basin, with the Fe concentration climbing from 3.0 wt.% at the head of the loch to ~5.5 wt.% in the basin sediments. Core Y:Z11 (2) has considerably lower Fe concentrations ~2 wt.%, indicating the special nature of this core. The differences in distribution between Fe and Mn could be due to three reasons. Firstly Fe is more associated with detrital material, and thus the large background concentration ~3.0 wt.% in all the cores masks the considerable increase in concentration. Secondly Fe is reduced at a lower Eh than Mn so its concentration peaks are lower in the sediment than Mn, and it is less easy for the quantities of Fe associated with this peak to be introduced to the water column. Thirdly Fe could be associated with particles of larger grain size, and thus would not be as likely to be transported to the deep basin. Certainly the Fe cycle is decoupled from the Mn cycle as discussed in **5.2.**

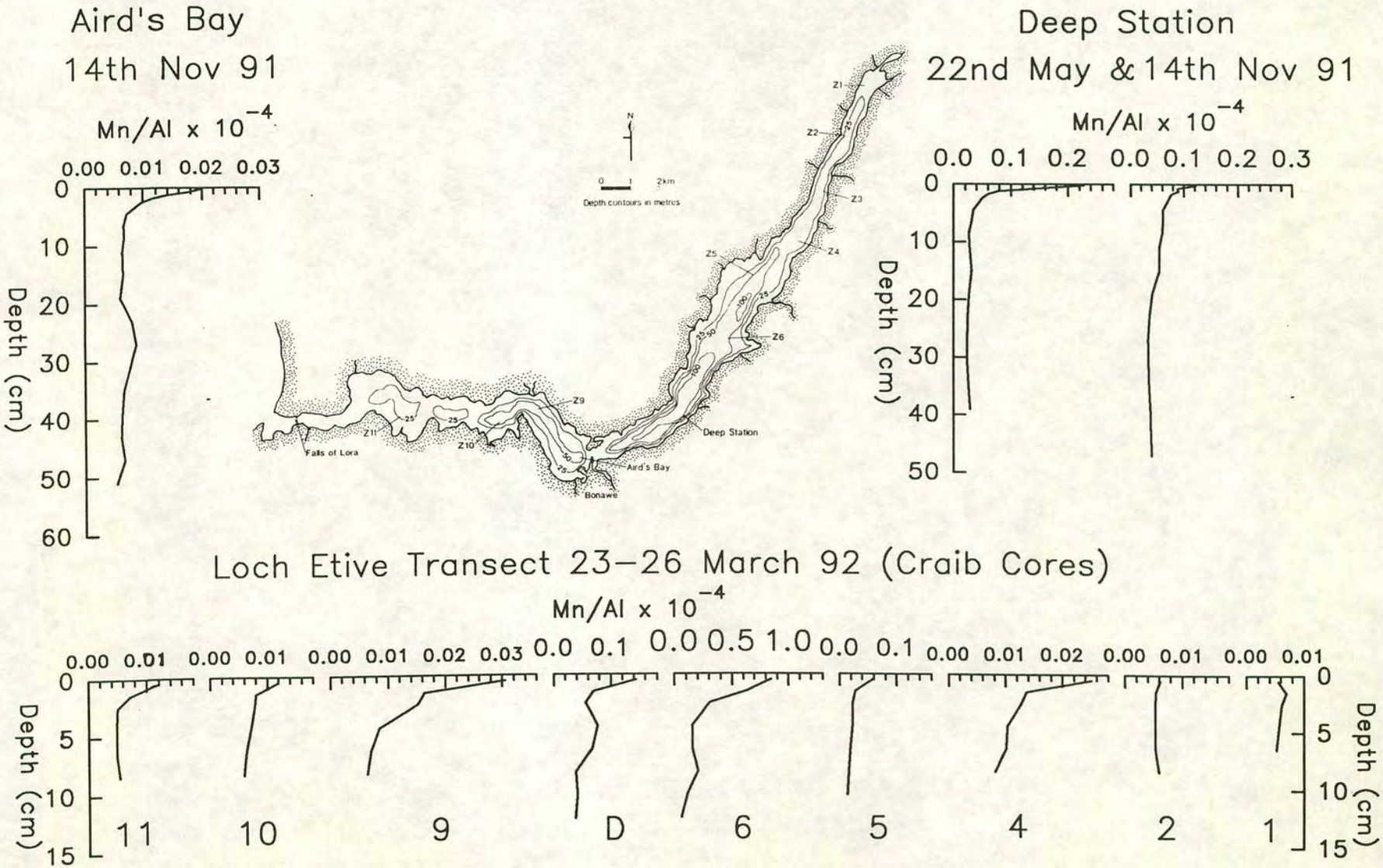


Figure 6.1.5. Mn/Al ratio in the sediments of Loch Etive, 1991-2. Note change in scale in the centre of the loch.

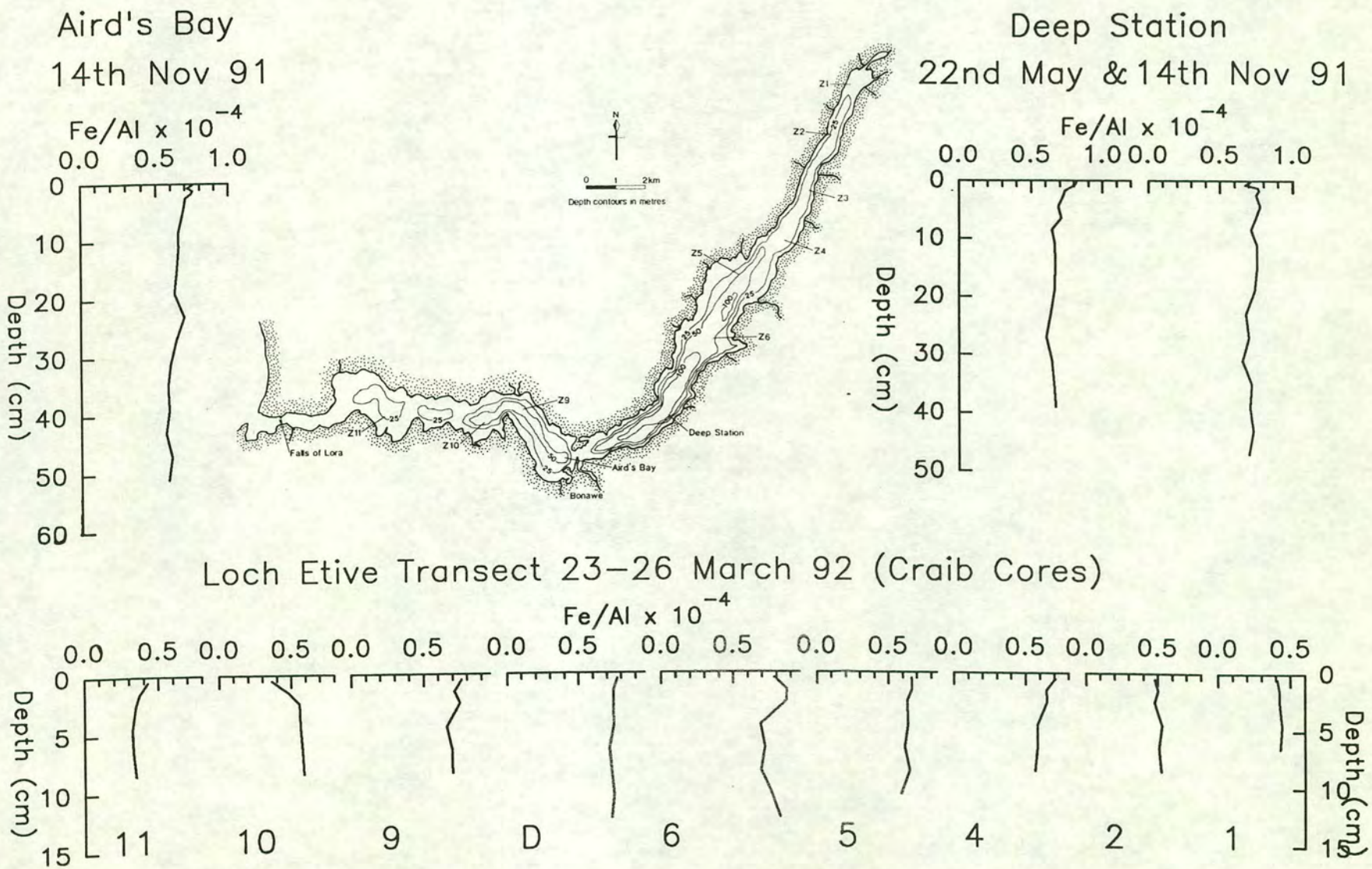


Figure 6.1.6. Fe/Al ratio in the sediments of Loch Etive, 1991-2.

Both Mn and Fe show expected profiles in the cores; Mn has a large narrow peak at the surface, Fe has a broader, less intense peak below that for Mn. The Mn and Fe concentrations in Loch Etive reported by the previous workers are consistent with those from this study. S:LE1 (5) in the outer basin has a surface Mn/Al ratio of 0.012, almost identical to Y:Z10 (5), and S:LE3 (14) has a ratio of 0.26 which is close to that of Y:Z6 (15) and Y:Z5 (17). S:LE2 (10) however has a very low ratio for a deep basin core of 0.016. This core must have been taken from very close to the sill.

Organic geochemistry

The C_{org} concentration along the Loch Etive transect is plotted in **Fig. 6.1.7.** WILLIAMS *et al.* (1987) determined C_{org} concentrations in the surface sediment of a Loch Etive transect and reported a general increase from the mouth (<4.0 wt.%) to the head (7-8 wt.%) of the loch. They also noted spikes of low concentration where there were river outflows and hence dilution by detrital material. The transect taken for this study shows some differences. Firstly C_{org} concentrations in the outer basin (<1 to 2-3 wt.%) are lower than those found in WILLIAMS *et al.* (1987). In this study inorganic $CaCO_3$ was dissolved by weak acid, and the resultant organic C concentration determined. It is possible that either this step was not carried out in the WILLIAMS *et al.* samples (or that it was not carried out to completion), or that too much acid was added to the samples of this study causing hydrolysis and loss of organic material. A recent intercomparison study by KING *et al.* (1995) suggested that some organic material was lost in the processing steps carried out in this study (see **A2.6.**). Core Y:Z11 (2) contained shell-derived material and there was considerable bubbling produced on addition of acid. Secondly in the deepest part of the basin (cores Z6, Z5, Z4) many C_{org} concentrations greater than 8 wt.% are found. The low oxygen conditions above these cores allow higher concentrations of organic material to survive. It is possible that the concentration of oxygen decreased from 1981 to 1992 when the two sets of cores were taken. Lower oxygen conditions could be due to either faster oxygen utilisation (due to greater organic waste from mussel farming) or more infrequent renewal of bottom water (due to an increase in rainfall). There has been an above average rainfall in the last 10 years. Thirdly although the C_{org} concentrations at the head of the loch are similar to those of WILLIAMS *et al.* (1987), they are slightly less than those found in the deep basin, whereas the earlier study found concentrations slightly higher than the deep basin.

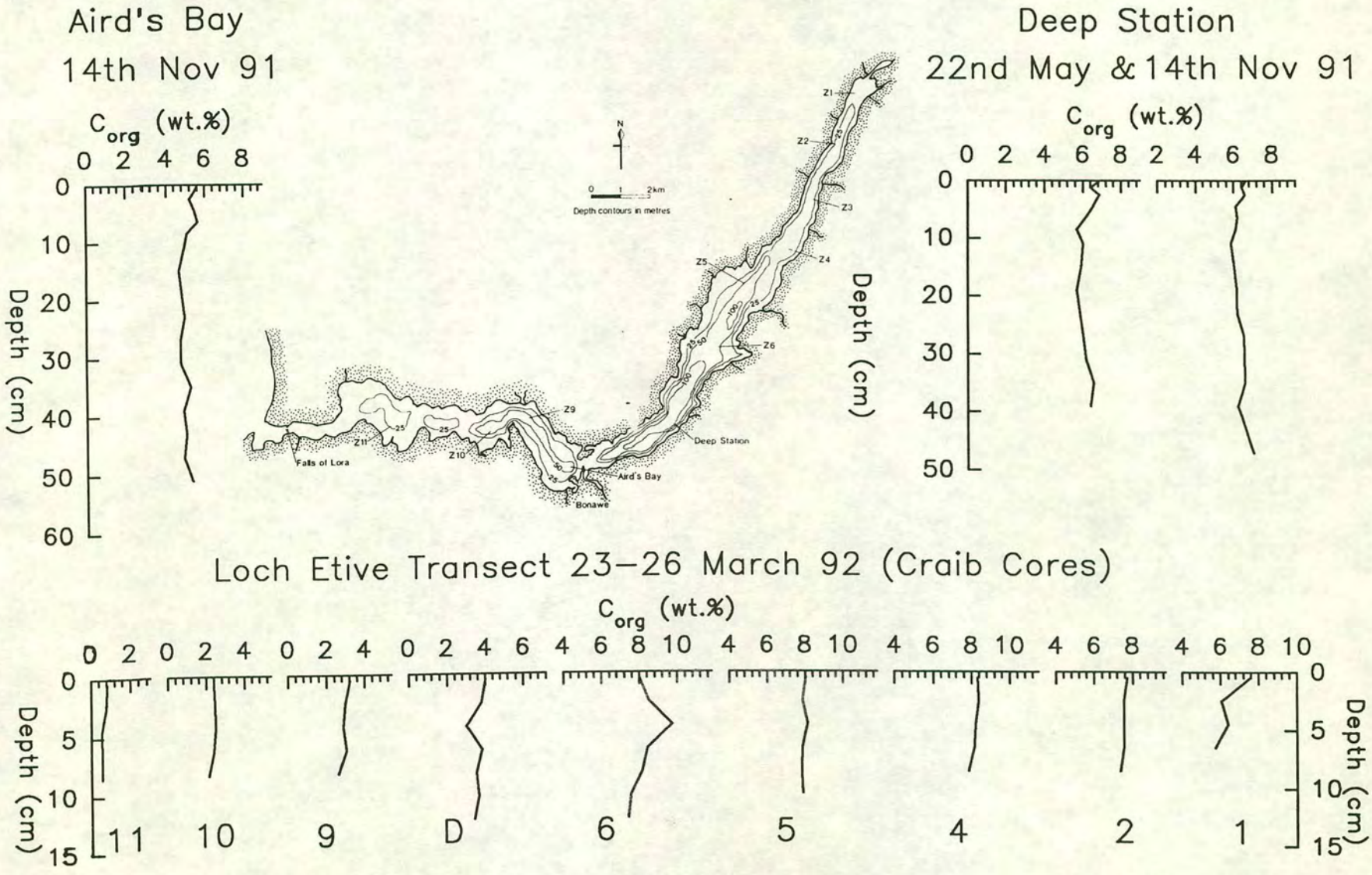


Figure 6.1.7. C_{org} concentration in the sediments of Loch Etive, 1991-2.

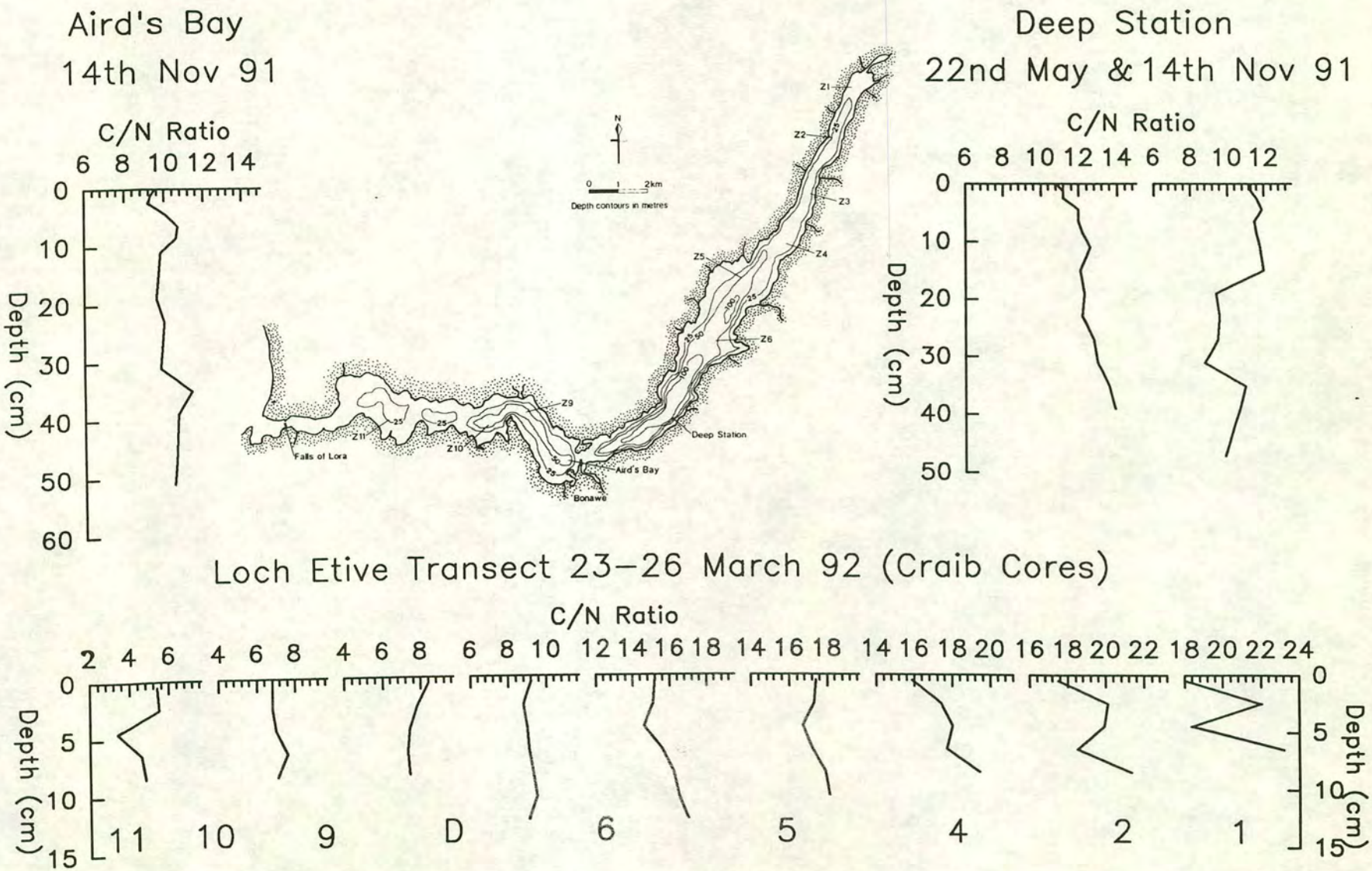


Figure 6.1.8. C/N ratio in the sediments of Loch Etive, 1991-2.

The C/N ratio is plotted in **Fig. 6.1.8.** and shows an increase from the mouth (~5) to the head (~20) of the loch. The C/N ratio in surface samples was previously reported as ranging from 7.3 to 14.2 by MALCOLM (1981) who postulated a simple end member mixing model to explain this distribution. He determined the C/N ratios of Loch Etive plankton (5.2) and River Etive terrestrial material (17.3), and assumed that each sample taken was a mixture of these two sources, and thus determined the proportions of 'marine C_{org}' in each sample. The C/N ratio reaches higher levels in this study as this transect extended further up the loch than that of MALCOLM (1981).

Copper, Lead and Zinc

There is generally an enhancement in the heavy metal concentration of the top 30-40cm of the Etive cores over the background concentrations lower down. MALCOLM (1981) pointed out that this may be due to either their diagenetic remobilisation or anthropogenic pollution in the past century. He assumed that there should be little heavy metal pollution in Loch Etive due to its remoteness from industry. The maximum and minimum concentrations recorded by previous workers in Loch Etive are tabulated in **Table 6.1.1.** Previous workers have only made a distinction between inner and outer basin cores when comparing concentrations, however maximum metal concentrations are found in those cores taken from the deepest parts of each basin. The older XRF results tend to be more erratic, and include some isolated extremely high results which I have assumed to be erroneous and not included in **Table 6.2.1.** Newer results tend to have smoother profiles, and perhaps more weight should be given to these results. If the cores of MALCOLM (1981) are discounted for this reason then the deep basin shows larger heavy metal concentrations than the outer basin, as would be expected since the Mn, Fe and porosity results are all larger and the grain size lower.

The Cu/Al ratio along the Etive transect is plotted in **Fig. 6.1.9.** Highest concentrations of Cu are found in the outer basin (cores B (8) and Z9 (7)) where the concentration can reach 27 mg kg^{-1}. In the deep basin typical concentrations of 20 mg kg^{-1} are found. However this is an effect of comparing cores from unique locations, not entirely representative of the whole basin. Other workers Cu concentrations can reach 35 mg kg^{-1} in both basins. Along the transect of the inner basin, the Cu concentration increases from the head of the loch to the deep basin. Core B has enhanced surface Cu concentrations, while the other long cores do not

display such an increase. Super-imposed on this is a surface (0-2cm) depletion of Cu seen in all the basin cores.

Table 6.1.1. Range of heavy metal concentration in Loch Etive sediment cores. The transect number of WILLIAMS *et al.* (1987) is given in parenthesis to enable comparison. Some unrepresentative maximum values have been discarded from the early cores.

Core code	Heavy Metal Concentration (mg kg^{-1})			Reference
	Cu	Pb	Zn	
ET-1A (25)	7-17	38-59	67-97	RIDGWAY (1984)
5F (16)	10-29	31-100	73-223	RIDGWAY (1984)
LE3 (14)	4-19	28-96	81-245	SHIMMIELD (1993)
ET8-75/1 (13)	18-34	33-59	103-270	MALCOLM (1981)
ET8-75/2 (13)	20-33	37-65	99-268	
6F (13)	14-47	43-118	83-267	RIDGWAY (1984)
A (12)	5-18*	64-98	159-253	this study
C (12)	12-20	53-94	125-242	
3F (12)	12-35	37-103	82-238	RIDGWAY (1984)
ET3-A (12)	8-31	37-115	83-263	
ET1 (11)	20-33	41-90	97-245	O'DONNELL(1987)
LE2 (10)	3-15	21-60	91-177	SHIMMIELD (1993)
B (8)	12-24	43-98	115-240	this study
4F (7)	7-25	18-81	84-202	RIDGWAY (1984)
ET4-A (7)	14-35	40-108	98-235	
ET11-75/5 (7)	21-32	44-116	109-278	MALCOLM (1981)
ET11-77/1 (7)	14-28	37-108	97-279	
AB1 (7)	15-26	27-89	100-226	O'DONNELL (1987)
LE1 (7)	6-18	31-97	101-242	SHIMMIELD (1993)
8F (1)	1-12	15-59	56-136	RIDGWAY (1984)

*Minimum value found at surface, not at depth

The Pb/Al ratio along the Etive transect is plotted in **Fig. 6.1.10.** There is a more obvious surface enrichment in Pb than for Cu, with all three long cores showing a three-fold increase from background levels to surface levels. This more obvious increase is due to the wider-ranging nature of Pb pollution due to it's atmospheric distribution. The Pb concentration found in the basin cores is higher than the head and mouth, with the highest concentrations found in the deepest samples. This may be a grain size effect, with Pb most associated with clays. SHIMMIELD (1993) determined the $^{208}Pb/^{206}Pb$ and $^{206}Pb/^{207}Pb$ ratios in her Etive cores to investigate their Pb pollution history. She concluded that there was significant Pb pollution in the sediments of Loch Etive from early 1900 onwards, with petrol derived Pb commencing in the 1930's and increasing to 40% of the total pollutant Pb by the 1960's. The Pb ratios do not show any evidence of Pb mobility.

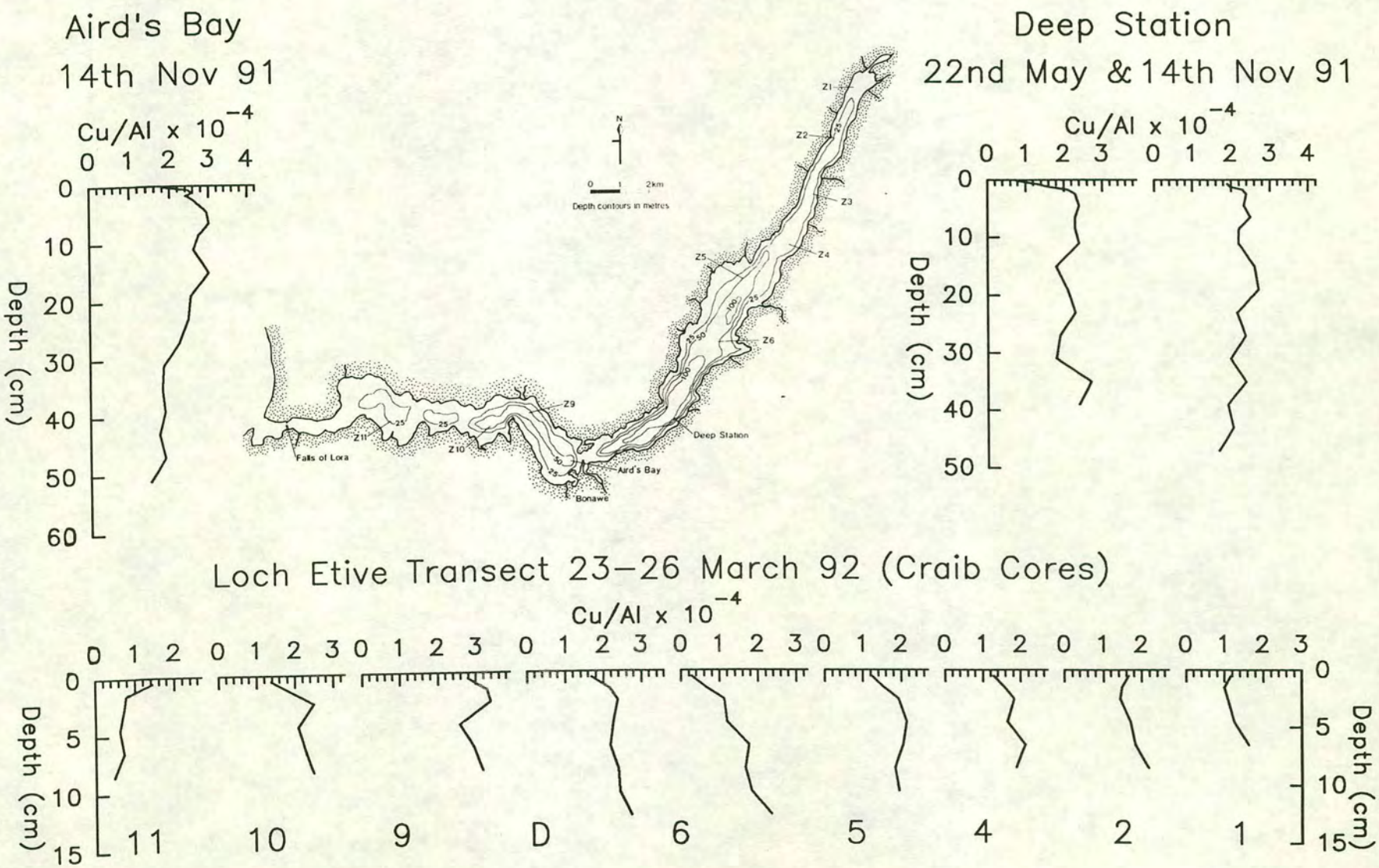


Figure 6.1.9. Cu/Al ratio in the sediments of Loch Etive, 1991-2.

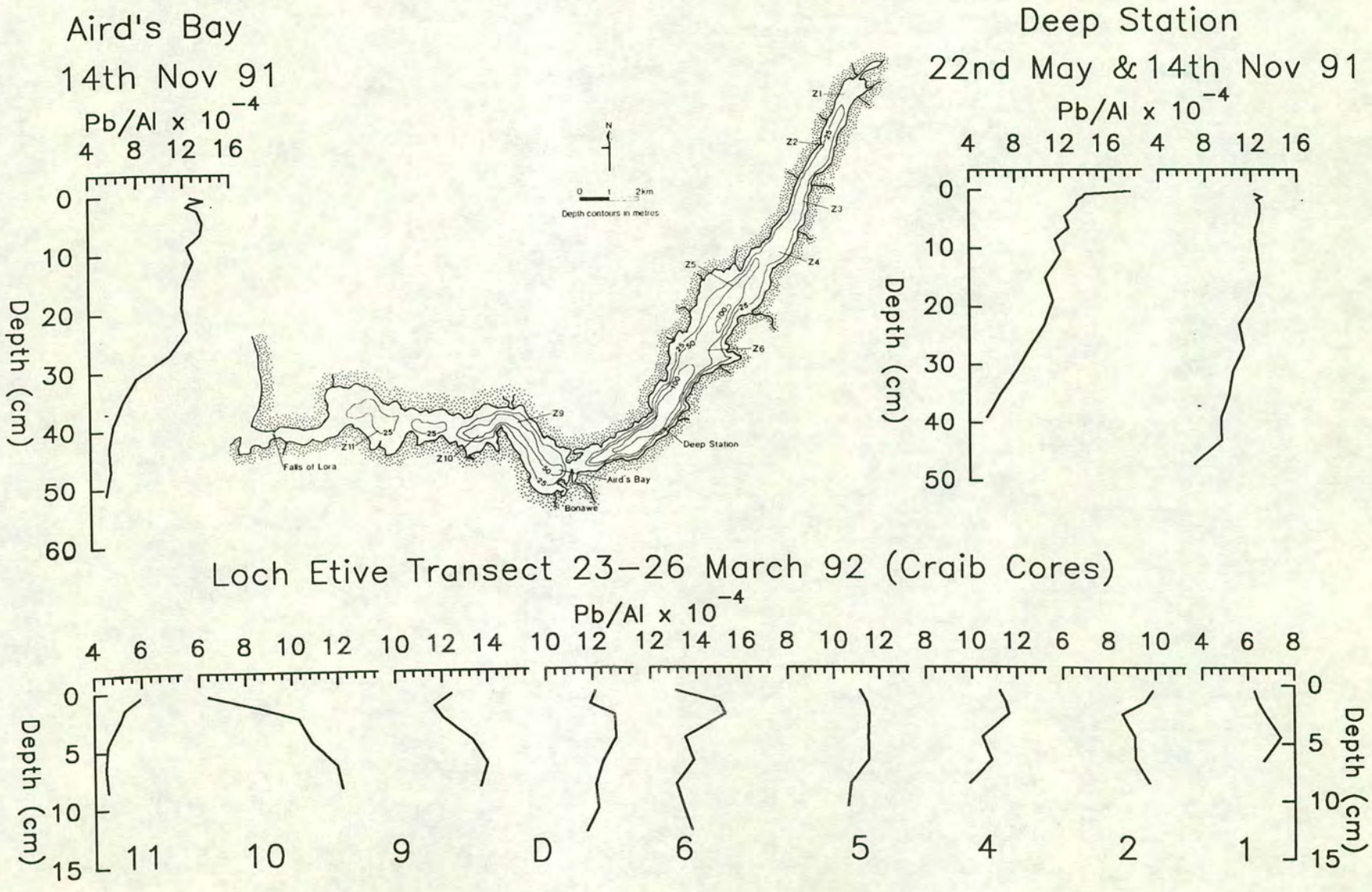


Figure 6.1.10. Pb/Al ratio in the sediments of Loch Etive, 1991-2.

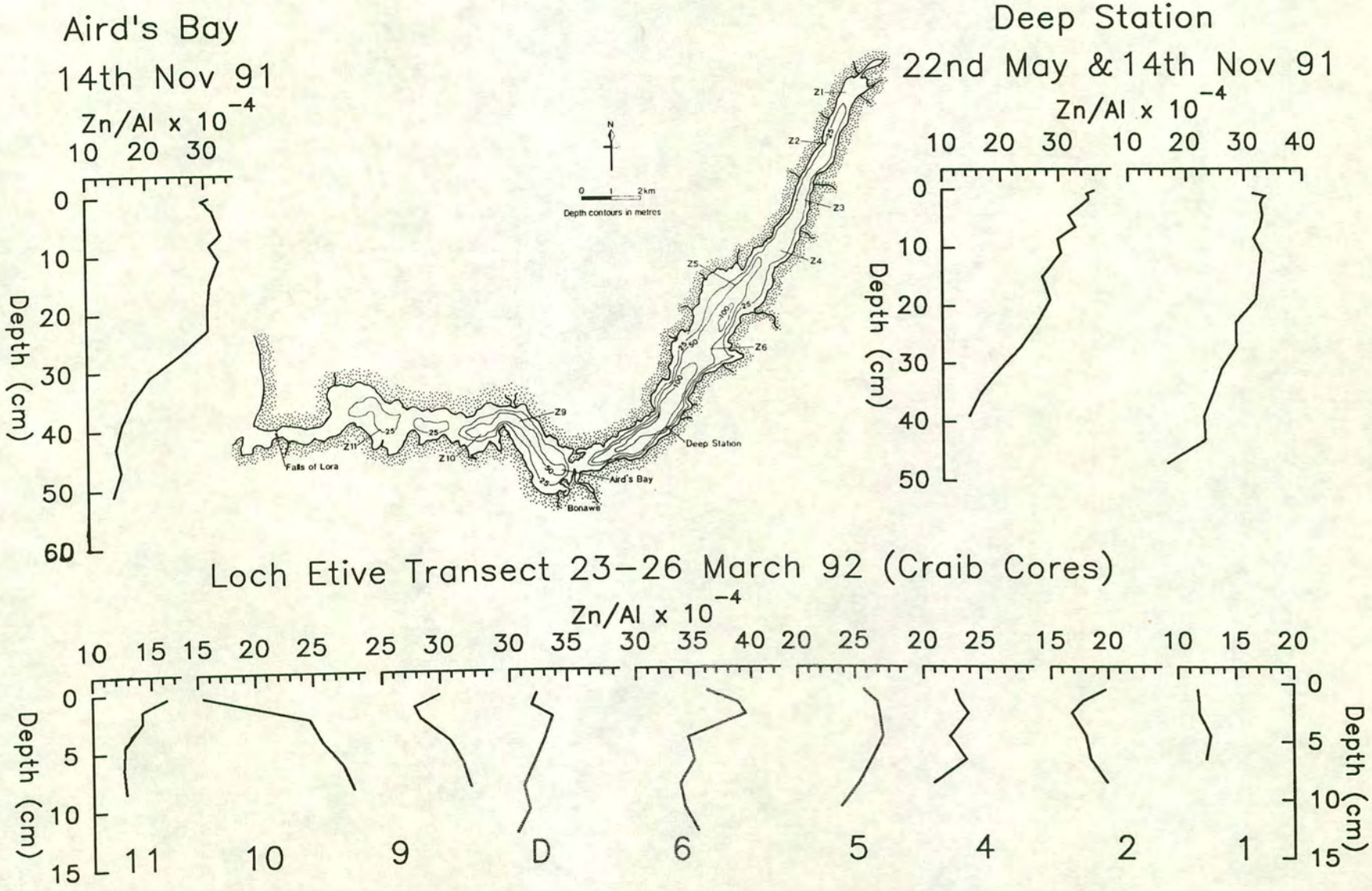


Figure 6.1.11. Zn/Al ratio in the sediments of Loch Etive, 1991-2.

The Zn/Al ratio along the Etive transect is plotted in **Fig. 6.1.11.** There is an obvious increase in Zn along the transect as the depth of the core increases, with the maximum value found in the deepest core, Z6 (15). This could be a grain-size effect. Similarly there is an obvious surface enrichment in the long cores, with Zn concentration rising threefold from its value at 40cm to that at the surface. This could be due to anthropogenic pollution or diagenetic mobilisation.

6.2. Sediment Radiochemistry

^{210}Pb Profiles

^{210}Pb was determined in the long cores and transect cores to estimate the accumulation rate of the cores and to estimate the ^{210}Pb flux to the sediment for comparison with that estimated by the sediment traps. The ^{210}Pb activities for cores A, B and C are tabulated in Appendices **B1.5.**, **B2.5.**, and **B3.5.** respectively, and plotted in Figures **6.2.1.**, **6.2.2.**, and **6.2.3.** respectively. ^{226}Ra was not determined, so excess ^{210}Pb was estimated by subtracting an average value of 30 Bq kg^{-1} from total ^{210}Pb. SHIMMIELD (1993), found little variation in ^{226}Ra activities in three Loch Etive cores with means and standard deviations of: 33.2 ± 4.8, 32.8 ± 3.7 and 36.9 ± 5.4 Bq kg^{-1}. While this is obviously not completely satisfactory, as ^{226}Ra anomalies can occur, the error introduced is not overwhelming. Using the C.I.C. model (see **1.3.**) the gradient of a plot of ln excess ^{210}Pb versus depth in g cm^{-2}, is equal to $-\lambda / \omega$. The gradient was estimated by a simple linear regression. The accumulation rates resulting have been tabulated in **Table 6.2.1.** with all previous workers' accumulation rates included for comparison. The rates found in this study compare well with those determined by RIDGWAY (1984), but less favourably with those of SHIMMIELD (1993). Core S:LE2 (10) was taken from the steep slope close to the sill, explaining the very low accumulation rate found there, while S:LE1 and S:LE3 may be lower as they are also taken from slope areas. The accumulation rates for some of the transect cores have been estimated but since these cores do not contain the whole ^{210}Pb record, the rates obtained are estimates with large ranges. Indeed outside of the deep basin the cores do not extend past the mixing zone into the zone of decay so an estimation of the accumulation rate has not been attempted.

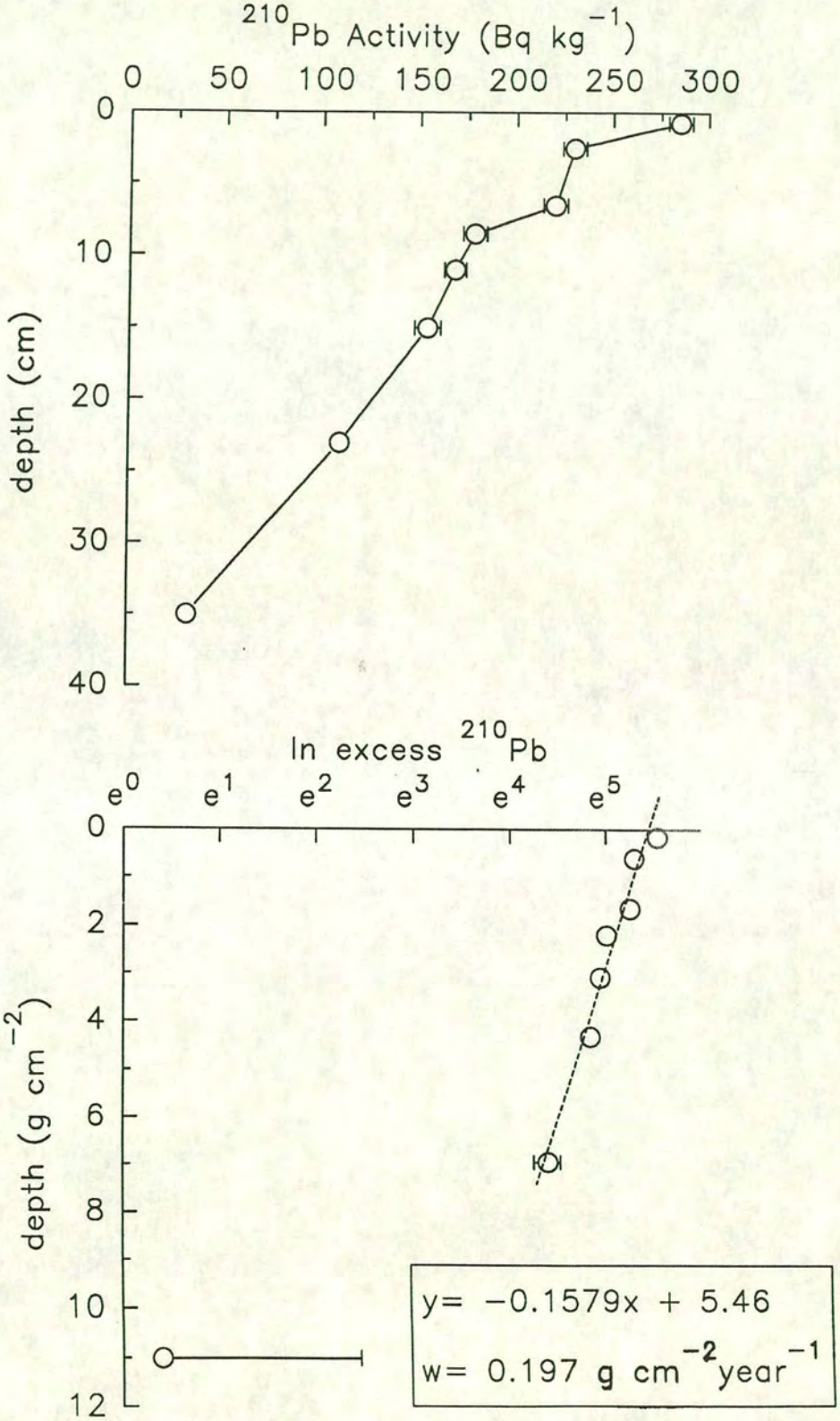


Figure 6.2.1. Core A (Deep Station, 22.5.91), ^{210}Pb activity plotted against depth in cm (upper) and ln excess ^{210}Pb plotted against depth in g cm^{-2} (lower). Horizontal error bars representing uncertainty in the ^{210}Pb determination, mainly from counting statistics, are shown where larger than symbol size.

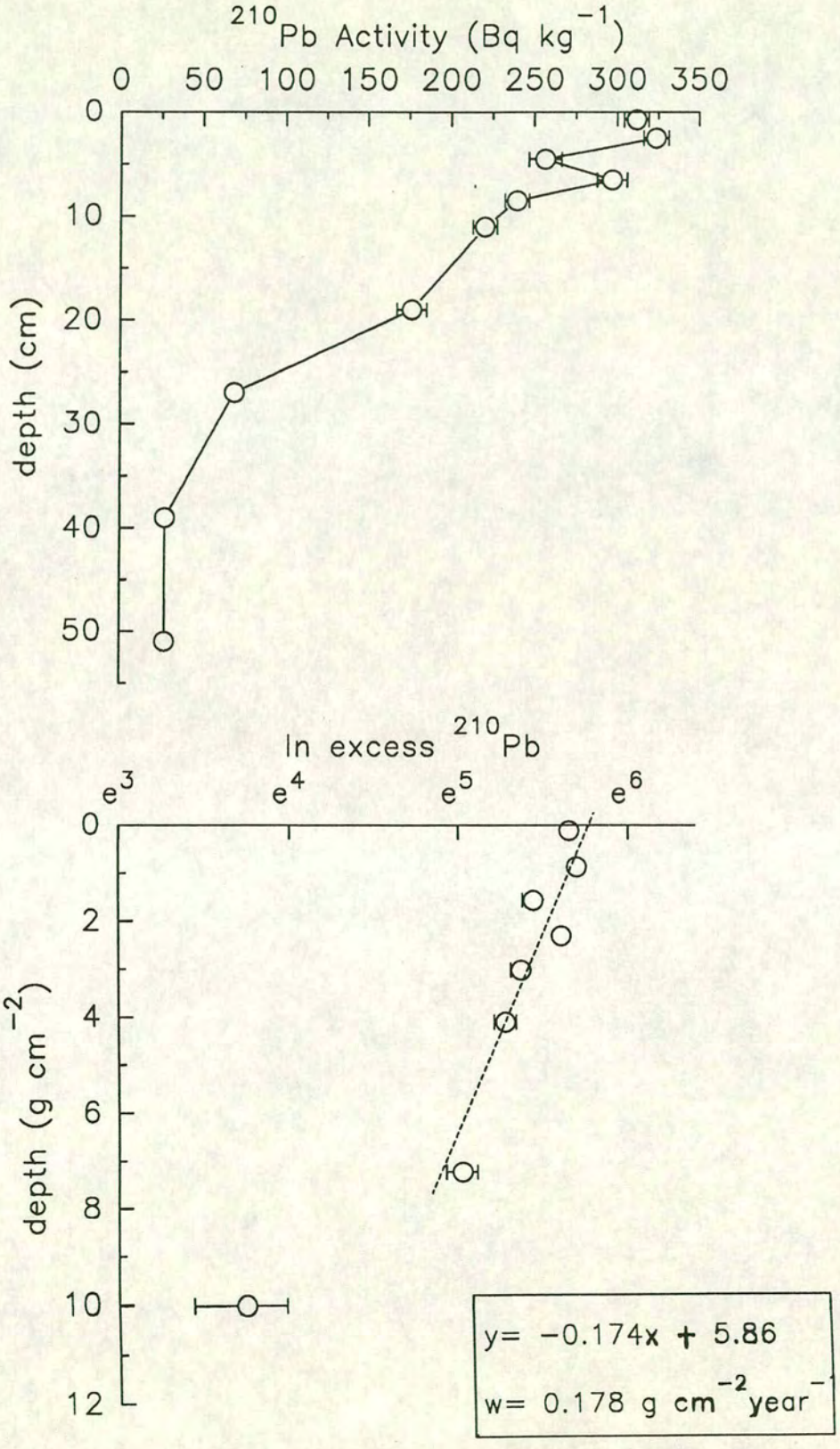


Figure 6.2.2. Core B (Aird's Bay, 14.11.91), ^{210}Pb activity plotted against depth in cm (upper) and ln excess ^{210}Pb plotted against depth in g cm^{-2} (lower). Horizontal error bars as Fig. 6.2.1.

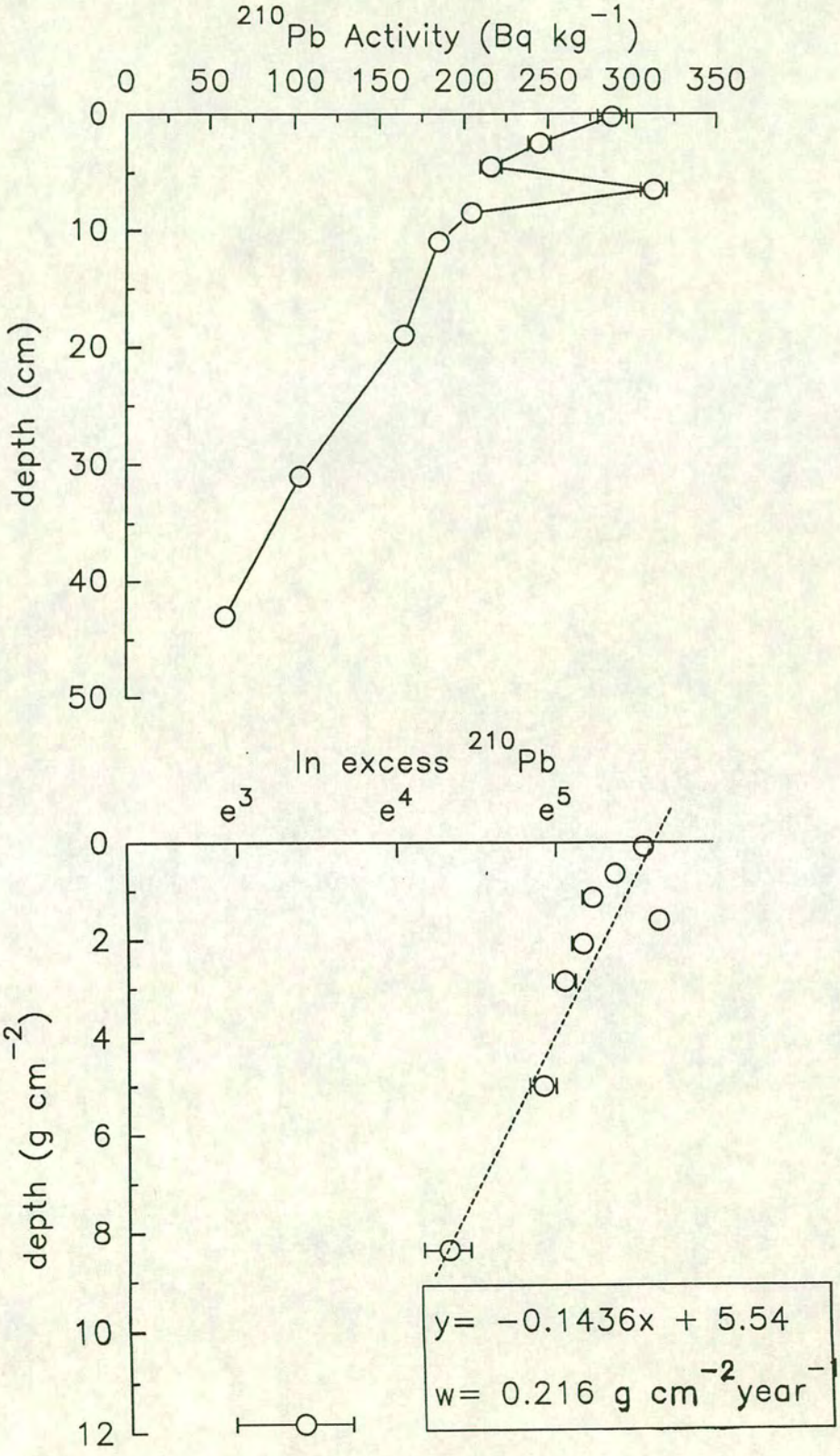


Figure 6.2.3. Core C (Deep station, 14.11.91), ^{210}Pb activity plotted against depth in cm (upper) and ln excess ^{210}Pb plotted against depth in g cm^{-2} (lower). Horizontal error bars as Fig. 6.2.1.

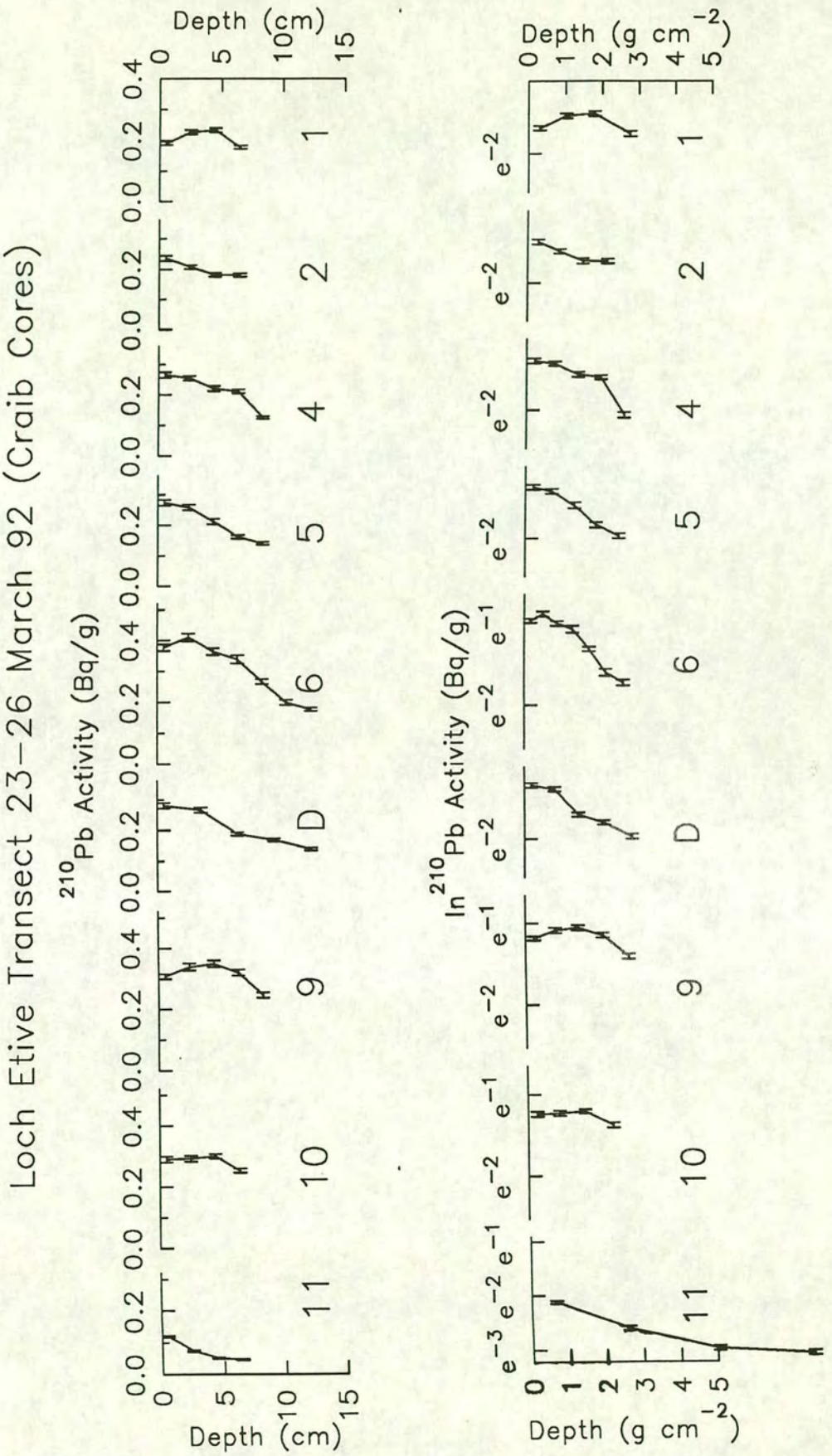


Figure 6.2.4. Transect core ^{210}Pb plotted against depth in cm (upper) and ln excess ^{210}Pb plotted against depth in g cm^{-2} (lower). Horizontal error bars as Fig. 6.2.1.

There is also a difference between the two possible methods of estimating accumulation rates from ^{137}Cs results. In the depth of penetration method, the lowest depth that ^{137}Cs appears in the core is assumed to be the onset of Sellafield-^{137}Cs effluent i.e. 1952 (SHIMMIELD, 1993) however if Cs is mobile in the sediment this point would be moved downwards thus giving an over-estimation of the accumulation rate. In the ^{137}Cs-maxima approach the depth in which the maximum concentration of ^{137}Cs appears is taken as the date of maximum discharge i.e. 1975 (SHIMMIELD, 1993). The peak should be broadened by mixing but the mid-point of the peak will remain unchanged. Both O'DONNELL (1987) and SHIMMIELD (1993) point out that the rates obtained by RIDGWAY (1984) by the depth of penetration method are over-estimates and that if rates are estimated using his data by the maximum peak method there is no discrepancy between ^{137}Cs and ^{210}Pb rates. The difference between these rates was one reason for RIDGWAY & PRICE (1987) suggesting that ^{210}Pb was mobile in Loch Etive sediments.

Table 6.2.1. ^{210}Pb and ^{137}Cs derived accumulation rates in long cores A (Deep Station, 22.5.91), B (Aird's Bay, 13,11,91) and C (Deep Station, 13,11,91), in selected transect cores (23-26,3,92) and in the cores of SHIMMIELD (1993) and RIDGWAY (1984). The equivalent transect position from WILLIAMS *et al.* (1987) is also given.

		sediment accumulation rates g cm^{-2} yr^{-1}		
Transect No.	Core code	^{210}Pb	^{137}Cs-maxima	^{137}Cs-depth of penetration
25	R ET1-A			0.59
17	Y Z5			
15	R 5F Y Z6			0.35
14	S LE3	0.064	0.07	0.22
12	Y A Y C Y ZD R LES-2 R 3F	0.197 0.216 0.29		 0.36 0.35
10	S LE2	0.038 - 0.068	0.18	0.22
8	Y B	0.167		
7	R LES-1 R 4F	0.13		0.48 0.67
6	Y Z9			
5	S LE1	0.10	0.10	0.31

Table 6.2.2. ^{210}Pb inventory and flux to the sediment in long cores A (Deep Station, 22.5.91), B (Aird's Bay, 13,11,91) and C (Deep Station, 13,11,91), in the transect cores (23-26,3,92) and in the cores of SHIMMIELD (1993). The equivalent transect position from WILLIAMS *et al.*, (1987) is also given.

Transect No.	Core code	^{210}Pb Inventory (Bq cm^{-2})	^{210}Pb flux to sediment (Bq m^{-2} $year^{-1}$)
25	Y Z1	0.68-0.83	211-259
23	Y Z2	0.51-0.64	161-199
19	Y Z4	0.61-0.64	190-200
17	Y Z5	0.63-0.67	196-210
15	Y Z6	0.83-0.86	260-267
14	S LE3	0.77 ± 0.11	238 ± 33
12	Y A Y C Y ZD	1.07 1.42 0.62-0.67	330 439 192-209
10	S LE2	0.22 ± 0.03	68 ± 9
8	Y B	1.81	559
6	Y Z9	1.00-1.31	312-409
5	S LE1 Y Z10	0.95 ± 0.15 1.21-1.47	296 ± 47 379-458
2	Y Z11	0.48-0.50	148-155

The inventory of excess ^{210}Pb was also calculated, and by multiplying the inventory by the ^{210}Pb decay constant, the steady state flux to the sediment of ^{210}Pb is obtained. The ^{210}Pb inventory and the ^{210}Pb flux to the sediment for the three long cores are shown in **Table 6.2.2.** The cores from this study have inventories and steady-state fluxes considerably higher than those in SHIMMIELD's cores, though this may be due to differences between the cores relative positions, rather than differences in methodology. The inventory and flux to sediment have been estimated for the transect cores, but as most of the excess ^{210}Pb is not contained in the core, these are no more than rough estimates and a possible range of values is given.

The excess ^{210}Pb sediment inventories found in Loch Etive show similar variation to other coastal marine areas, examples of which are tabulated in **Table 6.2.3.** The inventories range from 0.22 Bq cm^{-2} in S:LE2 (10), which is similar to sandy deposits in the Irish sea and coastal regions of the USA, to 1.81 Bq cm^{-2} in Y:B (8) which is as large as mud banks on the North Atlantic Shelf. The excess ^{210}Pb sediment inventories presumably vary with grain size in Loch Etive, with the largest inventories found in the deep basin where the grain sizes are smallest.

Table 6.2.3. Literature examples of excess ^{210}Pb sediment inventories.

Location	excess ^{210}Pb inventory ($Bq\ cm^{-2}$)	Reference
Scottish freshwater lochs:		BRYANT, 1993
a) R. Loch of Glenhead (south-west)	0.27, 0.30	
b) Loch Lomond (central-west)	0.23, 0.49	
c) Loch Coire nan Arr (north-west)	0.54	
New England lakes, USA	0.40 ± 0.30 (0.15-1.32, n=14)	DAVIS *et al.*, 1984
Norwegian lakes	0.37 ± 0.08 (0.26-0.54, n=13)	DAVIS *et al.*, 1984
Clyde sea lochs, Scotland		SHIMMIELD 1993
a) Loch Long	0.77	
b) Loch Goil	0.67	
c) Loch Fyne	0.31, 0.22	
Saanich Inlet, Canada	1.0, 2.7	MATSUMOTO & WONG, 1977
Puget Sound, western USA	1.08 ± 0.5 (n=35)	NEVISSI, 1987
Chesapeake Bay, eastern USA	0.80 ± 0.34 (0.37-1.47, n=7)	HELZ *et al.*, 1985/6
northeast USA coastal bays and inlets	0.66 ± 0.43 (0.15-1.30, n=7)	BUESSELER *et al.*, 1985/6
North Atlantic Shelf, northeast USA:		BUESSELER *et al.*, 1985/6
a) fine grained deposits	1.36 ± 0.44 (0.85-2.33, n=16)	
b) sandy deposits	0.00 ± 0.00 (0.0-0.0, n=4)	
north east Irish Sea:		MCCARTNEY *et al.*, 1990
a) muddy deposits, St Bees Head.	0.90 ± 0.27 (0.48-1.41, n=10)	
b) sandy deposits	0.34 ± 0.15 (0.01-0.61, n=18)	
North Atlantic Slope, northeast USA:		BUESSELER *et al.*, 1985/6
a) 200-1000 m	1.26 ± 0.37 (0.83-1.52, n=3)	
b) 1000-2000 m	1.05 ± 0.32 (0.60-1.33, n=4)	
c) 2000-4000 m	0.58 ± 0.18 (0.35-0.80, n=5)	
d) 4000-6000 m	0.34 ± 0.10 (0.18-0.48, n=7)	

6.3. Pore water geochemistry and radiochemistry

Pore water concentrations of phosphate, Fe and Mn in Core F (Deep Station, 18.1.93) were determined to investigate the geochemistry and redox status of the pore water. The methods used are reported in Appendices **A3.2.** and **A3.3.**, while the results are tabulated in Appendix **B7.1.** Pore water ^{210}Pb was determined by combining samples to produce a volume of pore water large enough to enable alpha spectroscopy to be carried out, albeit with long counting times. The method used is reported in Appendix **A3.4.**, and the results are tabulated in **Table 6.3.1.** Solid phase geochemistry or radiochemistry was not investigated in Core F - the solid phase was assumed to be identical to Cores A and C (Deep Station 22.5.91 and 13.11.91 respectively).

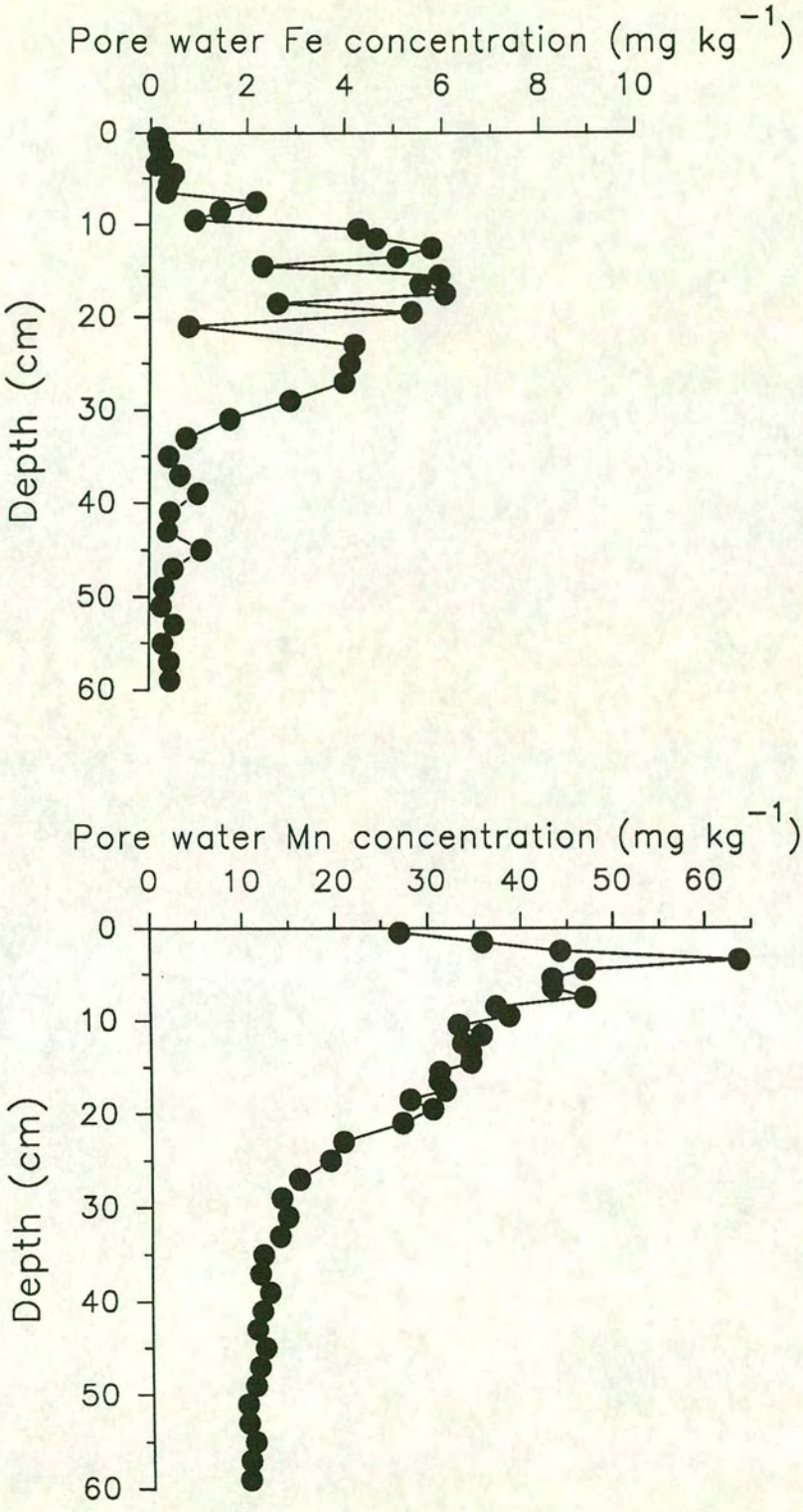


Figure 6.3.1. Pore water Fe (upper) and Mn (lower) concentration in Core F (deep station, 18th January 1993). Error bars are shown where larger than symbol size.

Pore water Fe and Mn concentrations are plotted in **Fig. 6.3.1.** There is a sharp Mn concentration peak in the upper centimetres of the core, and a broader Fe peak lower in the core than the Mn peak. This is as predicted by the Eh of the Mn and Fe couples (see **1.2.**). The Mn pore water concentration of Core F (12) has a peak greater than 60 mg l^{-1} at 3-4 cm and falls off to a background concentration of 10-11 mg l^{-1} below 30 cm. These concentrations are considerably greater than those determined by RIDGWAY (1984) in ET3-A (12) where the peak of 18 mg l^{-1} was found in the uppermost sample and the background concentration was ~1 mg l^{-1}.

Only a handful of pore water ^{210}Pb determinations have previously been carried out, as large volumes are needed. WAN *et al.* (1987) combined the pore water from a large depth range of a core from Griefensee, Switzerland, and reported a ^{210}Pb activity of 22 Bq m^{-3}. BENOIT & HEMOND (1991) determined a depth profile of pore water ^{210}Pb activity in two cores from Bickford Pond, Ma, USA. Their results are tabulated in **Table 6.3.1.** with one of three similar profiles obtained by COCHRAN & KRISHNASWAMI (1980) from the North Equatorial Pacific. All five literature profiles show a peak in pore water ^{210}Pb activity at around 4-5 cm depth, however in Loch Etive, this peak was at the surface. Biological mixing in the other locations will tend to displace the ^{210}Pb solid profile downwards, and hence the pore water profile will follow. The deep basin of Loch Etive has limited biological mixing however, so the ^{210}Pb solid profile occurs at the surface. Additionally the Etive results are lower than the literature results, about 10 times lower than Bickford pond, and around 4 times lower than the deep ocean sediments.

Table 6.3.1. ^{210}Pb pore water activity in Loch Etive (this study), Bickford Pond, Ma. (BENOIT & HEMOND, 1991), and the North Equatorial Pacific (COCHRAN & KRISHNASWAMI, 1980). Note the two different depth scales: g cm^{-2} and cm.

Depth (g cm^{-2})	^{210}Pb activity (Bq m^{-3})	Depth (cm)	^{210}Pb activity (Bq m^{-3})	Depth (cm)	^{210}Pb activity (Bq m^{-3})
Bickford Pond (August '85)		**N. Equatorial Pacific (Core B)**		**Loch Etive deep station (Jan. '93)**	
0.00-0.19	47 ± 4	0-1	11.8	0-1	8.52 ± 1.01
0.19-0.50	68 ± 5	1-2	8.5	1-3	5.28 ± 0.90
0.50-1.06	63 ± 5	3-4	7.3	3-6	4.13 ± 0.68
1.06-1.65	88 ± 8	4-5	25.2	6-9	1.23 ± 0.52
Bickford Pond (September '85)		7-9	29.5	9-12	2.68 ± 0.53
0.00-0.13	73 ± 8	11-13	18.3	12-16	3.13 ± 0.61
0.13-0.54	61 ± 6	17-19	19.2	16-20	2.90 ± 0.51
0.54-1.22	110 ± 13	23-25	8.7	20-26	1.80 ± 0.42
1.22-2.04	96 ± 13	31-34	5.8	26-30	1.59 ± 0.56
2.04-2.71	60 ± 7	37-40	9.7	30-36	2.80 ± 0.44
2.71-4.00	33 ± 5			36-40	1.97 ± 0.58

The pore waters were not degassed following collection, so a proportion of the ^{210}Pb activity may be due to in-growth from ^{222}Rn after extraction. BENOIT & HEMOND (1991) addressed this problem however, and calculated that only ~4 % of the determined ^{210}Pb came from ^{222}Rn support in their cores.

Several authors (GAILLARD *et al.*, 1986; GOBEIL & SILVERBERG, 1989; BENOIT & HEMOND, 1991) have interpreted the following as evidence of Pb remobilisation: (1) the presence of steep concentration gradients in pore water ^{210}Pb or Pb concentration, and (2) pore water ^{210}Pb or Pb concentrations higher than the overlying water. In Etive there was a peak in ^{210}Pb pore water concentration, indicating mobility, and the pore water concentration was greater than the overlying water, indicating release from the sediments.

As well as their pore water evidence, BENOIT & HEMOND (1991) found independent evidence of ^{210}Pb mobility out of Bickford Pond sediments. However in Loch Etive the independent evidence suggests *immobility* (the stable Pb ratios of SHIMMIELD, 1993; the agreement of ^{210}Pb and ^{137}Cs dates). It may be possible that the quantity of mobile or released ^{210}Pb is insufficient to affect either the solid phase or water column ^{210}Pb distributions.

A notable feature of the ^{210}Pb pore water profile is that it resembles the solid phase ^{210}Pb profile, mimicking the main peak at the surface and a minor peak at ~15 cm depth. It is possible that the pore water ^{210}Pb represents one side of an equilibrium with solid phase ^{210}Pb. In this scenario ^{210}Pb would be constantly desorbed to the dissolved phase and re-adsorbed onto solid particles, without any vertical movement. Vertical movement is not impossible, just unlikely as a dissolved ^{210}Pb nuclide is much more likely to come into contact with a solid particle and be adsorbed. For such a mechanism to produce the profile found, the kinetics of ^{210}Pb adsorption must be faster than those of diffusion, so that thermodynamic principles can be established.

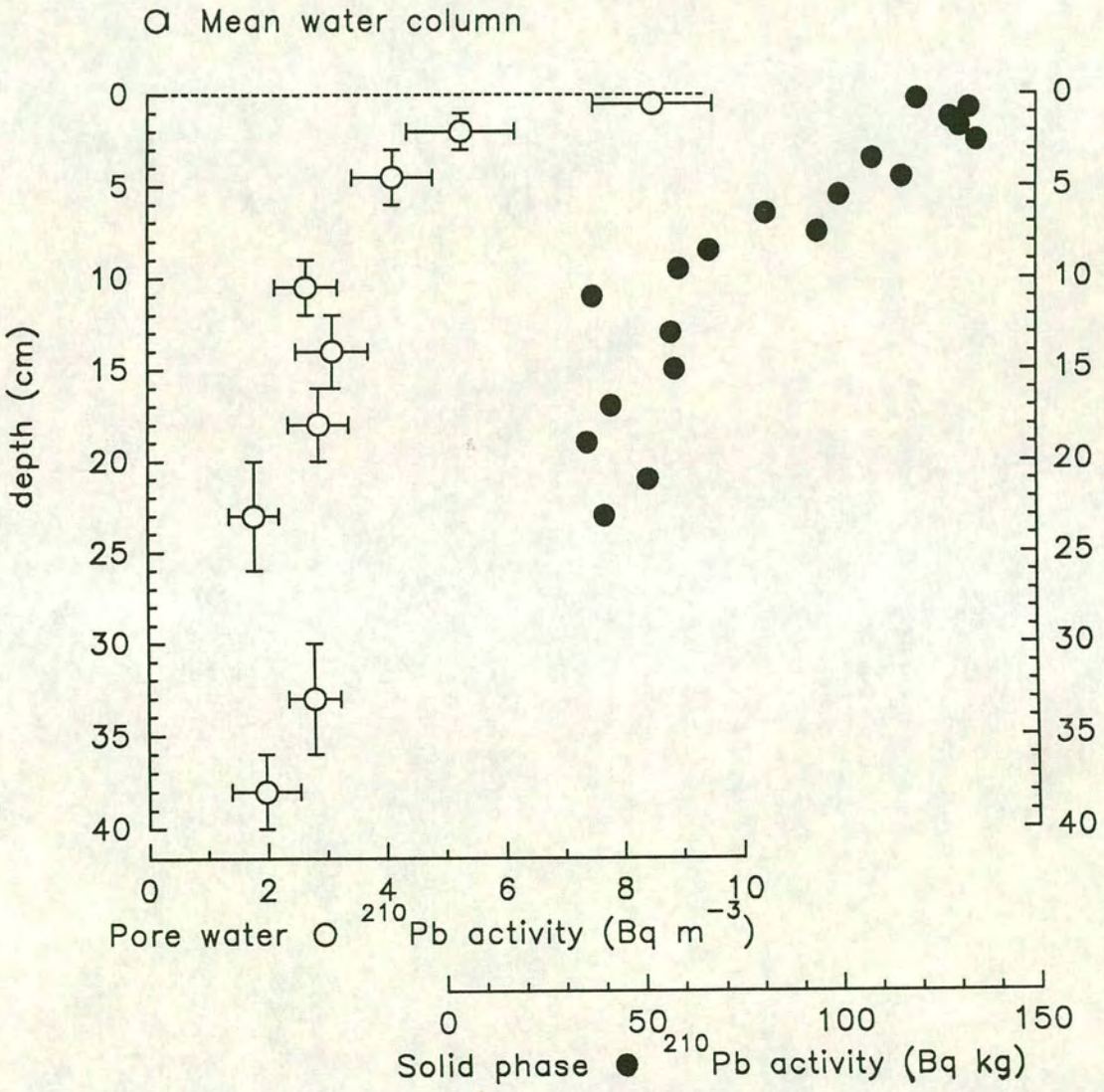


Figure 6.3.2. Pore water ^{210}Pb activity in Core F (left) with solid phase ^{210}Pb activity in Core A (right) for comparison. Horizontal error bars representing uncertainty in the ^{210}Pb determination, mainly from counting statistics, are shown where larger than symbol size. Vertical error bars represent the depth range over which the pore waters were combined. Mean bottom water ^{210}Pb activity also shown.

The interaction of radionuclides with particles is conveniently described by an apparent distribution constant, K_d , which was defined by BENOIT & HEMOND (1991) as:

$$K_d = \text{solid } ^{210}Pb \text{ activity / dissolved } ^{210}Pb \text{ activity} \qquad \textbf{Eqn. 6.3.1.}$$

where the activities are given in Bq m^{-3}. Any variation in K_d with depth implies that a reversible adsorption/desorption equilibrium is not established. The apparent K_d was determined at each depth to test the equilibrium theory, and the results are tabulated in **Table 6.3.2.** In the two cores of BENOIT & HEMOND (1991) the ^{210}Pb distribution coefficient peaked at the surface (14900 in one core and 8500 in the other) and tailed off to ~1500 at depth. In Loch Etive, K_d has similar values as Bickford Pond, but the trend is reversed. However, the profile is more spiky, suggesting that any variation is due to analytical uncertainty, and not vertical movement of ^{210}Pb. This doesn't rule out some limited vertical transport of ^{210}Pb, but the evidence is not as clear as in Bickford Pond, where an increase in the deep water radionuclide activity was also found. In Etive, even if there was some release of ^{210}Pb to the water column it is clear that the quantity of any ^{210}Pb or ^{210}Po released is too small to change the water column (**4.3.**) or sediment (**6.3.**) radionuclide inventories.

Similar results were found for $^{239+240}Pb$ and ^{241}Am in the Irish Sea by MALCOLM *et al.* (1990). Other evidence (see **1.4.**) suggested that these particle-reactive nuclides were immobile, but there was a small variation in K_d with depth, indicating that the system was slightly out of equilibrium. However calculations indicated that any diffusive flux out of the sediment would be too small to alter inventories.

Table 6.3.2. ^{210}Pb distribution coefficient (K_d) calculated from pore water activities in Core F and solid phase activities in Core A.

Depth (cm)	Pore water ^{210}Pb activity (Bq m^{-3})	Solid phase ^{210}Pb activity (Bq kg)	Density (g cm^{-3})	Solid phase ^{210}Pb activity (Bq m^{-3})	partition coeff. (K_d)
0-1	8.52	126.5	0.169	21300	2500
1-3	5.28	132.3	0.222	29400	5500
3-6	4.13	108.2	0.258	27900	6800
6-9	BDL	81.1	0.270	21900	-
9-12	2.68	45.1	0.296	13400	5000
12-16	3.13	58.3	0.309	18000	5700
16-20	2.90	39.5	0.326	12900	4400
20-26	1.80	46.2	0.339	15700	8700
26-30	BDL	-	-	-	-

6.4. Summary

Loch Etive is separated into basins by rocky sills where fast currents are common. Close to the sills, the sediment accumulates slowly, has a high grain size, is less porous than elsewhere and is deficient in heavy metals, Mn and ^{210}Pb. Inflowing water, either daily tides or infrequent density renewals, resuspends fine sediment from the slopes and carries it into the centre of the loch where it is redeposited. Thus the sedimentation rate increases with depth, while the grain size decreases. The porosity also increases with depth, with exceptionally porous sediments found in the deep basin. The Mn concentration increases with depth, and is massively enriched in the deepest part of the loch. Fe increases too, but not by as much, as Fe is not recycled as intensively as Mn. The heavy metal and ^{210}Pb concentration show an increase with depth, presumably because they are associated with fine particles.

The excess inventory of various elements are tabulated in **Table 6.4.1.** The background concentration of each element was estimated by comparing the concentrations found at the bottom of the long cores with that found in the cores at the head of the loch. For most elements they were similar, and using these values in the inventory calculation produced good results for all the transect cores, except for Z11 (2) which appears to be a special case; this method produced negative results for Fe, Cu and Pb. The transect cores do not contain the entire excess inventory of each element. The quoted inventories are thus underestimations.

Table 6.4.1. Loch Etive transect and long core Mn, Fe, Cu, Zn, Pb ^{210}Pb and C_{org} excess inventories.

			inventory of element within core *					
	depth of core		Mn	Fe	Cu	Zn	Pb	^{210}Pb
	cm	g cm^{-2}	mg cm^{-2}	mg cm^{-2}	mg cm^{-2}	mg cm^{-2}	mg cm^{-2}	Bq cm^{-2}
Z 1	7	2.76	0.053	3.64	0.0035	0.009	0.0063	0.489
Z 2	8	2.54	0.015	18.4	0.0125	0.126	0.0525	0.422
Z 3	7	2.50	0.173	9.78	0.0167	0.110	0.0416	0.226
Z 4	9	2.66	1.19	37.3	0.0132	0.210	0.0822	0.488
Z 5	10	2.85	3.38	45.7	0.0161	0.292	0.0963	0.475
Z 6	14	2.94	39.1	73.3	0.0113	0.483	0.151	0.751
Z D	13	2.93	11.8	72.5	0.0270	0.444	0.129	0.523
Z 9	9	2.80	1.29	64.0	0.0413	0.409	0.143	0.793
Z 10	8	2.73	0.478	29.2	0.0246	0.302	0.0936	0.672
Z 11	8	8.86	0.175	-	-	0.071	-	0.288
A	40	12.43	23.7	242	0.102	1.26	0.325	1.07
B	54	19.59	2.23	329	0.146	1.67	0.578	1.81
C	50	13.63	40.2	318	0.113	1.58	0.537	1.42

*these are underestimations, as some of the excess peak is not contained within the transect cores.

Chapter 7 : Conclusions

7.1. ^{210}Pb Flux Comparison

The ^{210}Pb flux to the sediment has been estimated via the mass balance box model (**4.4.**), sediment core inventories (**6.3.**) and sediment traps (**5.3.**). These fluxes are compared in **Table 7.1.1.** There is good agreement between the flux determined in the deep traps, 5 m above the sediment surface, and the flux estimated from sediment core inventories. Thus the deep trap records accurately the ^{210}Pb flux to the sediment. There is no cycling of material, via resuspension and redeposition, in the deepest part of Loch Etive, as this would result in a deep trap flux greater than the core-derived flux. Material resuspended from the shallower parts of the loch is laterally advected to the deep basin and hence the flux through the traps increases with depth.

Table 7.1.1. ^{210}Pb fluxes at the deep station estimated via a mass balance box model, sediment traps, and inventories in cores A, and C.

	^{210}Pb flux (Bq m^{-2} yr^{-1})	
	box-model	sed. traps
surface	300	7.71
intermediate	299	131
deep	298	398
sediment	330, 439	

The flux estimated *via* the box-model, while in the correct order of magnitude, does not compare well with the sediment trap flux. Perhaps the most important assumption made in the model was that the riverine input was spread evenly over the entire loch. This is unlikely, as the input is at point sources around the loch. The evidence of WILLIAMS *et al.* (1987) and ANSELL (1974) also shows that sedimentation is not homogeneous across the entire loch. The box-model has actually determined the ^{210}Pb flux averaged across the loch as if sedimentation was homogeneous. At shallow depths, sedimentation rates are above average close to river mouths; in the centre of the loch however the surface trap records a below-average flux.

Both daily tidal inflow and aperiodic density inflow resuspend material and carry it into the deep basin, in increasing amounts as depth increases. Thus mid-depths in the deep basin record fluxes close to average, and deep traps record fluxes above average. This is illustrated in **Figure 7.1.1.**

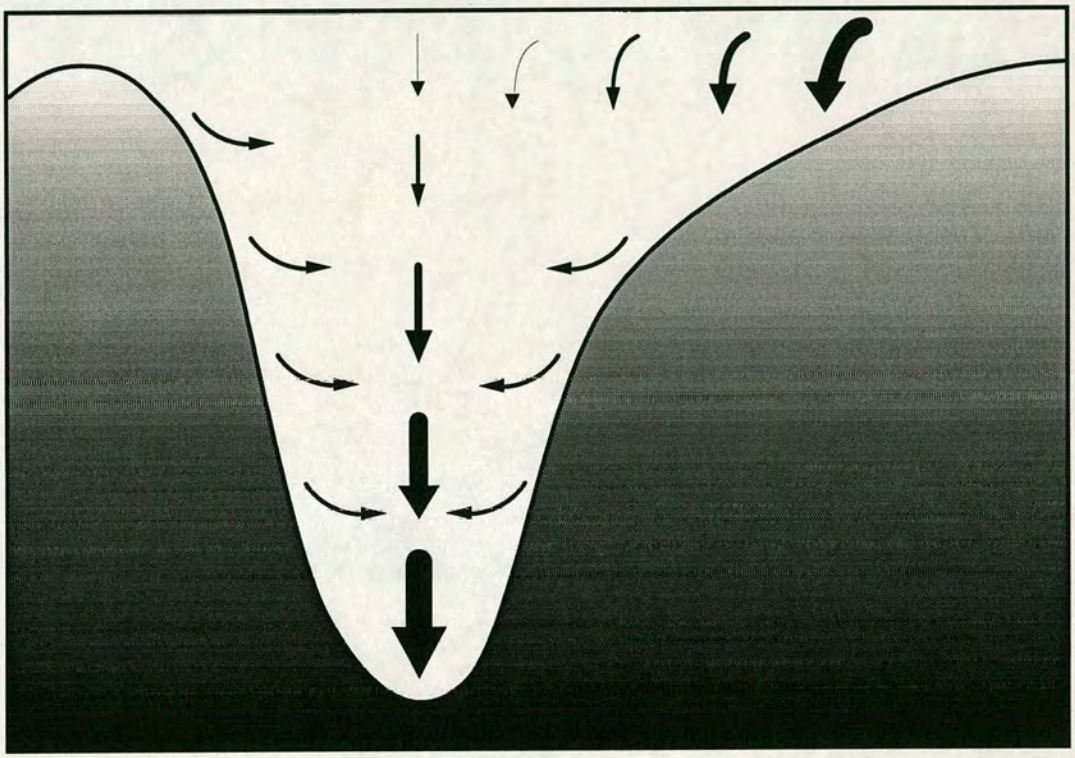


Fig. 7.1.1. Schematic of sediment transport in the deep basin of loch Etive.

Another assumption made in the model was that the flow of ^{210}Pb over the Bonawe sill was balanced. It seems likely that some ^{210}Pb is carried out of the loch, if only because the net transport of water must be out of the loch. This would result in the model over-estimating the sedimentary flux of ^{210}Pb.

A schematic representation of the size and direction of the ^{210}Pb fluxes within the deep basin of Loch Etive is shown in **Fig. 7.1.2.** Particulate fluxes are represented by solid symbols, dissolved fluxes by clear symbols. Both the rainfall flux and the supported flux from decay of ^{226}Ra are presumed to be to the dissolved phase only. The net transport of ^{210}Pb over the Bonawe sill is unknown as is the net dissolved transport between the boxes. The increasing sedimentary ^{210}Pb flux in the centre of the loch was determined *via* the sediment traps, while the rest of the fluxes were calculated using the box model.

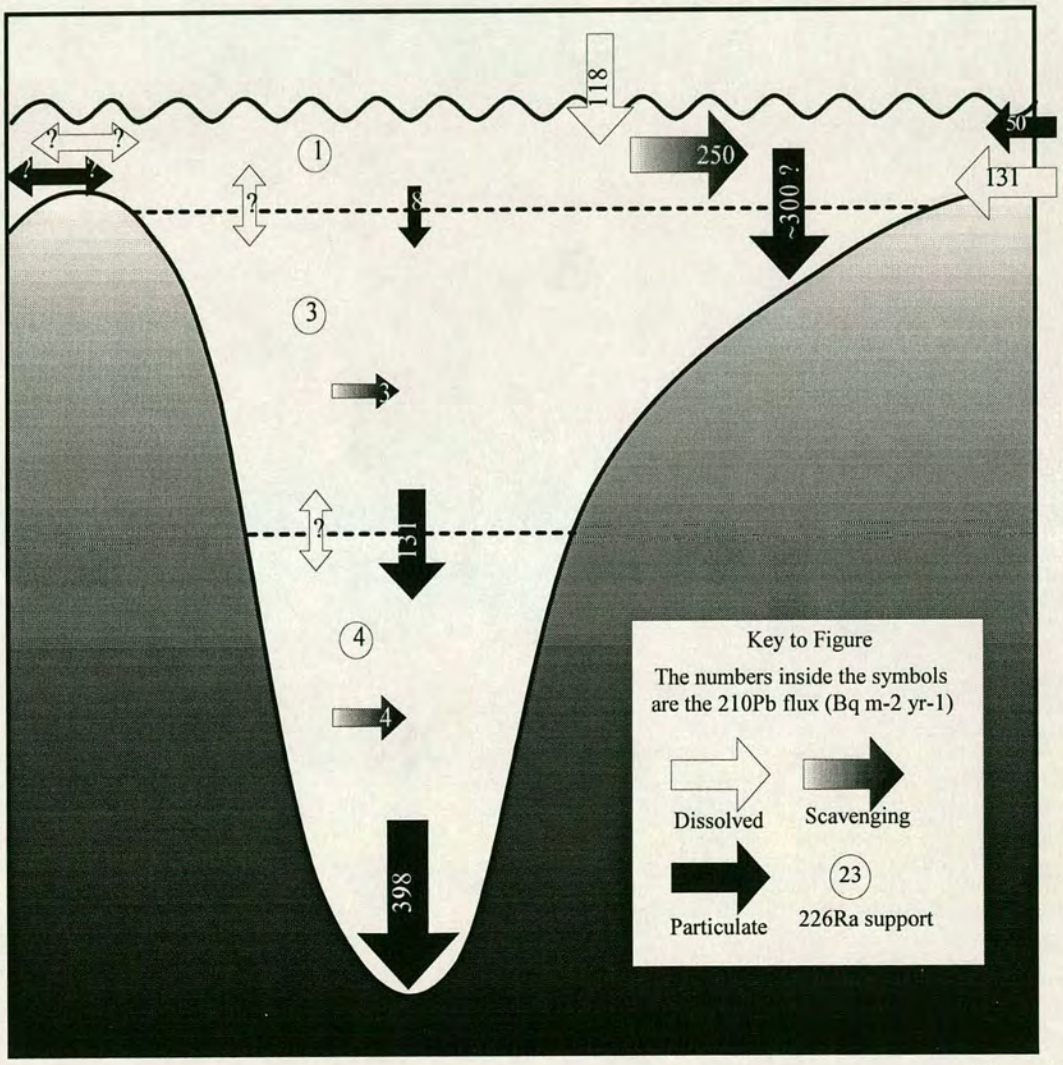


Figure 7.1.2. Schematic of ^{210}Pb fluxes in the deep basin of Loch Etive.

7.2. Conclusions

A number of conclusions can be drawn from this study. Foremost of which is that ^{210}Pb has only very limited mobility, which is insufficient to affect the Loch Etive water column or sediment ^{210}Pb inventories. The water column ^{210}Pb and ^{210}Po results indicate that there is no measurable release from the sediments to the water column. The difference between ^{137}Cs and ^{210}Pb dating noted by RIDGWAY & PRICE (1987) is resolved by re-calculating the ^{137}Cs dates (O'DONNELL, 1987; SHIMMIELD 1993). SHIMMIELD (1993) also reports stable Pb ratios which indicate no Pb mobility. Another mechanism, rather than Pb mobility must be responsible for the correlation between I/C_{org} ratios and Pb/Al ratios noted by RIDGWAY & PRICE (1987). The ^{210}Pb pore water profile and the ^{210}Pb partition coefficients indicate that a limited amount of ^{210}Pb does mobilise from the sediment. Provided the validity of the other assumptions of the ^{210}Pb dating models are well considered for each case, ^{210}Pb can be used to date marine sediments.

It appears that there are serious questions regarding all the studies that have suggested ^{210}Pb mobility, except for the work of BENOIT AND HEMOND (1987, 1990, 1991) in Bickford Pond. However Bickford Pond is essentially a mad-made reservoir which has only been accumulating sediment since 1970. Perhaps ^{210}Pb is mobile here because of the artificial conditions. ^{210}Pb mobility should not be expected due to its high particle reactivity and high K_d.

There was an increase in dissolved ^{210}Po concentration at depth in the Loch Etive water column, but this is attributable to degradation of spring bloom plankton, containing large quantities of ^{210}Po, at depth in the months following the bloom. Regeneration of ^{210}Po increases in frequency and magnitude with depth. ^{210}Pb is not regenerated in the water column. Both ^{210}Po and ^{210}Pb are scavenged from the water column within days. It is likely that ^{210}Pb is scavenged by clay particles, which form flocculates when fresh and saline water mix, and Mn oxyhydroxides are involved. Fe minerals and organic material play little part in scavenging ^{210}Pb. The residence time of ^{210}Po in the surface waters increases ~10 fold in May '91, presumably due to recycling of organic material during the spring bloom.

The mean atmospheric flux is higher than previously determined at this general global position, but this may be due to the Loch Etive catchment area's higher average rainfall than elsewhere, rather than the statistical uncertainty of calculating

the yearly flux from a limited sample set. There is agreement with apparent ^{210}Pb rainfall fluxes estimated by other methods at west coast of Scotland sites.

Wide variations in the sedimentary ^{210}Pb record are found in different geochemical locations. Caution is thus advised in comparing cores from different sites, and in using lake or coastal cores to estimate atmospheric ^{210}Pb fluxes.

There were fewer deep water renewal events in the years of the study, than in the past. This is possibly due to the higher rainfall in recent years, preventing renewal from taking place. Consequently deep dissolved oxygen levels reached lower levels than had previously been determined. The speed at which deep water dissolved oxygen concentration falls, depends on the relative difference between mid-waters and deep waters, so renewal of the mid-waters is as important in deciding deep water oxygen concentration as deep water renewal. There is little evidence to suggest that fall-out of organic material from the fish-farming and mussel-farming industries affects oxygen concentrations at depth.

7.3. Improvements

There are a number of changes I would make to the sampling scheme with hindsight, which would have improved the project. Most notably the entire suite of samples should have been taken and analysed each month. This would have allowed better intercomparison of data set, seasonal trends would have been more apparent, and model calculations would have been more accurate. In particular each river and the rainfall should have been sampled each month. It would have been useful to take two rainfall samples each month (see **4.2.**); a whole month collection to determine the total input of ^{210}Pb, as well as a 12-hour collection to determine ^{210}Po concentrations.

It would have been useful to have determined ^{226}Ra activities in all the samples to estimate the fraction of total ^{210}Pb activity that is unsupported by in-situ radioactive production. This would have been especially useful in the riverine particulate samples - was the particulate ^{210}Pb activity in the mineral lattice, i.e. supported, or adsorbed onto its surfaces, i.e. excess. ^{210}Po should have been determined in the sediment trap samples, so that comparisons could have been made with ^{210}Pb.

It would have been useful to have determined the concentration of particulate material, and the major and minor element concentration in those particulates, in all the water column samples and in the river water samples. This would have allowed comparison of particulate radionuclide concentrations with particulate concentration - without this determination it is unknown whether increases in particulate radionuclide concentration are due to increases in the number of particles or increases in the radionuclide concentration of the particles. On one later field trip once the integrated study had finished a cast was carried out for SPM analysis.

It was recognised towards the end of the project that chlorophyll concentration could have been determined in the loch waters, and it was only determined in the last four months of the study. It would have been useful to determine it every month, so that carbon production calculations could have been carried out, and their seasonal nature investigated better. However super-saturation of oxygen was used to estimate production during spring bloom conditions.

7.4. Suggestions for Further Research

This project has illustrated the lack of knowledge about the mechanisms controlling the movement of ^{210}Pb and ^{210}Po in two separate areas of the hydrological cycle. The fate of these radionuclides introduced into lakes and estuaries is now understood, as traditionally research has focused on areas where anthropogenic pollutants are released into the environment. Yet if we are to use natural radionuclides as analogues of particle reactive heavy metal pollutants, we must understand their whole cycle from rock to sediment, via rainfall, fresh water, groundwater, ocean water, soil, and terrestrial and aquatic biota. In particular the mechanisms controlling the concentration of ^{210}Po in rain are poorly understood, as geochemists rarely determine rainfall ^{210}Po concentrations; also the fate of ^{210}Po and ^{210}Pb deposited on terrestrial catchment is poorly understood. Geochemists should collaborate with biologists, geographers, soil scientists and meteorologists.

Research could be done into how the atmospherically deposited radionuclides interact with the terrestrial catchment; to determine the most important pathways for ^{210}Po and ^{210}Pb, and their most important sources and sinks, and the timescale of

storage in each sink. Rivers and streams contain considerable concentrations of ^{210}Po and ^{210}Pb, yet the relative importance of each of the source pathways is unknown.

Is most radioactivity in streams a result of groundwater derived springs, direct atmospheric deposition onto water bodies, wash-off of atmospheric deposition from rocky surfaces, erosion of soil containing inventories of radionuclides, or of stream carried plant debris? How do the following factors affect each proportion: size of catchment compared to size of water body; type of land use; amount of rainfall; and natural decay series content of the local geology? After determining the volume of each component of the catchment area and the size of the transfer between them, simple box model calculations based on the inventories of ^{210}Po and ^{210}Pb in each component could reveal the importance of each pathway.

Also the speciation of ^{210}Po and ^{210}Pb in aquatic and terrestrial systems could be investigated by sequential extraction or fractionation techniques. I have postulated links between ^{210}Po and plankton, ^{210}Pb and Mn oxyhydroxides, and ^{210}Pb and terrestrial inorganics - it would be interesting to try and separate the components of marine particulate matter into terrestrial and marine organic and inorganic fractions and determine their ^{210}Po and ^{210}Pb activities.

The seasonality in the $^{210}Po/^{210}Pb$ ratio in rainfall (see **4.2.**) has illustrated the lack of knowledge of how ^{210}Po is incorporated into rainfall. Rainfall could be collected weekly to fully investigate any seasonal variation in the ^{210}Po and ^{210}Pb activities determined. The relationship between the $^{210}Po/^{210}Pb$ activity ratio and wind direction could be investigated. If there is a seasonal variation in the ratio, and an oceanic source is implicated, simultaneous determination of the $^{210}Po/^{210}Pb$ activity ratio in oceanic surface water and atmospheric samples could be carried out to test the theory proposed in **4.2.**

Finally, the processes controlling the distribution of ^{210}Pb in pore waters are certainly not understood, due in part to the need for large volumes of pore water for analysis. It would be useful to test the theory proposed in **6.4.** by investigating the ^{226}Ra-^{222}Rn-^{210}Pb-^{210}Po disequilibria in the pore water and solid phase of a box core, so that large enough volumes of water could be obtained from narrow depth ranges.

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A1. Water

A1.1. Sample collection

Deep water samples (10-20 l) were collected by multiple castings of 7 l polythene NIO water sampling bottles, and transferred to 20 l polythene carboys, with samples for nutrient and dissolved oxygen analyses reserved. All containers were rinsed out with small aliquots of sample. Surface and river samples were collected by emersing carboys in the water. Rain water was collected via run-off of an aluminium greenhouse roof into a carboy. A stand-alone pump (SAP) was deployed at depth. This filters, *in-situ*, large volumes (80-200 l) of water through 0.45 µm Azypor filters in parallel, and MnO_2 coated wound polypropelene cartridges in series.

Temperature and salinity were recorded on the downward cast of a NBA Environmental Systems Ltd. DMC-3M-U conductivity-temperature-depth bridge (CTD), connected to a TDS-7M electronic readout. Density (σ_t) was calculated from the salinity and temperature results using the polynomial equations given in FOFONOFF & MILLARD (1983):

$$\sigma(S,t,0) = \sigma_t = \rho(S,t,0) - 1000 \text{ kg m}^{-3}$$

$$\rho(S,t,0) = \rho_w + (b_0 + b_1t + b_2t^2 + b_3t^3 + b_4t^4)S + (c_0 + c_1t + c_2t^2)S^{3/2} + d_0S^2$$

where ρ_w , the density of pure water, $= a_0 + a_1t + a_2t^2 + a_3t^3 + a_4t^4 + a_5t^5$

and S is salinity, t is temperature and the constants are:

$a_0 = 999.842594$	$b_0 = 8.24493 \times 10^{-1}$	$c_0 = -5.72466 \times 10^{-3}$
$a_1 = 6.793952 \times 10^{-2}$	$b_1 = -4.0899 \times 10^{-3}$	$c_1 = 1.0227 \times 10^{-4}$
$a_2 = -9.095290 \times 10^{-3}$	$b_2 = 7.6438 \times 10^{-5}$	$c_2 = -1.6546 \times 10^{-6}$
$a_3 = 1.001685 \times 10^{-4}$	$b_3 = -8.2467 \times 10^{-7}$	
$a_4 = -1.120083 \times 10^{-6}$	$b_4 = 5.3875 \times 10^{-9}$	$d_0 = 4.8314 \times 10^{-4}$
$a_5 = 6.536332 \times 10^{-9}$		

A1.2 Dissolved nutrient analysis

400 ml water samples were filtered through Whatman GF/F filters as soon after collection as possible, and the filters and filtrate frozen until analysis. The filters were left overnight in 12.5 ml 93% methanol (GPR) to dissolve chlorophyll, and the extinction, determined on a spectrophotometer, at 665 nm compared to that at a background of 750 nm allowed the chlorophyll content to be calculated. Phosphate and silicate were analysed by standard wet-chemical spectrophotometric methods reported in STRICKLAND AND PARSONS (1968). The use of filtered water removed the problem of a variable turbidity blank. Oxygen was analysed by the Winkler titration (STRICKLAND AND PARSONS, 1968), on separate 250 ml samples in which the oxygen content had been fixed on board ship. Oxygen was also determined in-situ using a Yellow Springs International 5739 oxygen electrode fixed on the CTD.

A1.3 $^{210}Pb/^{210}Po$ sample processing and analysis

The samples were filtered through 0.45 μm Azypor filters, the filters reserved, and the filtrate acidified with 40ml conc. HCl as soon as possible after collection. Stable ^{206}Pb (0.5 ml) and 0.1 ml ^{208}Po were added to the filtrate as yield tracers. After allowing 2 days for tracer equilibration, the dissolved radionuclides were coprecipitated with 51 mg $CoNO_3$ and 1 g APDC (Ammonium pyrrolidine dithiocarbamate), and the green precipitate collected on Whatman GF/D filters.

The Azypor filters containing the particulate phase, were placed in acid washed Teflon beakers and yield tracers (0.5 ml stable Pb; 10 or 20 μl ^{208}Po) added. The filters were decomposed with 40 ml acetone (AnalaR), and the acetone fumed off. The residue was digested for approx. one hour with 20 ml HNO_3 (conc., AnalaR), 2 ml $HClO_4$ (60%, AnalaR) and 2 ml HF (AnalaR), then the acids fumed off to near dryness, to leave a yellow residue. Occasionally charring occurred to leave a black residue - this was taken up in 3-5 ml HNO_3 and fumed to near dryness once more.

The coprecipitate containing the dissolved phase was dissolved in 70 ml 95% acetone (AnalaR); 5% 0.1 M HNO_3, and filtered through 8 μm Nucleopore filters with acetone washings. The dark green solution was transferred to acid-washed Teflon beakers and the acetone fumed off. The residue was digested in 20 ml HNO_3 (conc., AnalaR) and 2 ml $HClO_4$ (60%, AnalaR) for approx. one hour and fumed to near dryness, to leave a rose pink residue.

The activity of ^{210}Po and ^{210}Pb was determined by the method of FLEER & BACON (1984). The residues from digestion were taken-up, with heating, in 10 ml of 1 M HCl and transferred, with washings, to an acid-washed glass beaker. To the solution was added 2.5 ml hydroxylamine hydrochloride 40%, to depress Fe interferences; 2 ml sodium citrate 25%; and 1 ml $Bi(NO_3)_2$, to act as a carrier for Po. The solution was made up to 50-90 ml with ultra-pure water, and the pH adjusted to 1.5-2.0. Polonium was auto-plated at 90 °C for 4 hours onto polished silver discs. After plating the solution was shaken overnight with a scrap of silver to ensure 100% removal of Po, and stored to allow in-growth. The silver discs were analysed on EG&G Ortec surface barrier alpha detectors connected to a multi-channel analyser. After 6-18 months ^{208}Po (20 μl) yield tracer was added to the solutions, which were left for at least 2 days for tracer equilibration. Polonium was auto-plated under the same conditions as the first plating step, and the silver discs analysed by alpha spectroscopy as before. The yield of stable Pb was determined by flame atomic spectroscopy (AAS) on a Varian spectrAA 300, with standards made up in a matrix prepared using the analytical reagents. If it is assumed that all the Po in the sample is removed at the first plating step then the activity of ^{210}Po present at the time of the second plating is proportional to the activity of ^{210}Pb present at the time of the first plating step. The activity of ^{210}Pb at the time of sampling is thus determined by correcting for loss during processing, and decay correcting back to time of collection. The activity of ^{210}Po at the time of sampling is determined from the first plating ^{210}Po concentration by correcting for in-growth of ^{210}Po from the ^{210}Pb activity, and decay correcting back to time of collection.

A1.4 SAP sample processing and analysis

The particulate filters were folded into quarters and reserved for analysis. The Manganese and associated radionuclides were stripped off the cartridges by cycling (using a peristaltic pump) 1.5 l of 1 M HCl with added hydroxilamine hydrochloride (10 ml, 20% w/v.) through them for 30 minutes, or until the cartridge appeared clear, followed by washes of 1 M HCl (1.5 l), and deionised water (1.5 l). The solution and washes were combined and $FeCl_3$ (25 mg) added, then the pH was adjusted to >7, precipitating $Fe(OH)_2$ which was collected on Whatman GF/D filters. The $Fe(OH)_2$ scavenges the radionuclides from solution. The filters were quartered and reserved.

A1.5 Gamma Spectroscopy

Folded particulate filters from the SAP were analysed, as soon as possible after collection to minimise ^{234}Th decay. It was hoped that the geometry of the quartered filters was reproducible. Standards were prepared by spiking blank filters with mixed radionuclide standards, drying under a heat lamp, and folding into quarters. Dissolved coprecipitate filters were also analysed, but at some time after sample collection, when all excess ^{234}Th will have decayed away. Standards were prepared by spiking 1 l of ultra pure water with mixed radionuclide standards and coprecipitating $Fe(OH)_2$ and the radionuclides onto Whatman GF/D filters which were folded into quarters.

A1.6 Suspended particulate analysis

500 ml aliquots of water were filtered through pre-weighed 0.45 μm Nucleopore filters, and reweighed when dry to determine total mass of suspended particulate matter (SPM). The weighings were carried out on a Perkin Elmer AD-2 7 figure balance. The filters were analysed by XRF (see **A2.4**) to determine Mn and Fe concentrations in the SPM.

A2 Sediment

A2.1 Sample collection

A slow-entry gravity corer (PEDERSEN *et al.*, 1985) was used to collect long cores (50-60 cm long, 8 cm diameter), while retaining the surface-water interface. There is a valve at the top of the corer to allow water flow-through, which eliminates pressure waves at the corer mouth. When penetration is complete, the release of tension on the cable closes the valve and the core can be retrieved with suction holding it in place. In practice, in relatively calm conditions, cores were regularly retrieved with clear supernatant water and apparently undisturbed interfaces, with the presence of fine scale features at the surface including a layer of flocculant. There appears to be little mixing down the sides of the core, as the large diameter barrel minimises friction. There was visual inspection of each core taken to check the quality of the interface. In addition short (7-13 cm long, 3 cm diameter) Craib cores (CRAIB, 1965), were taken. This slow-entry hydraulically dampened device is specifically designed to collect only short cores, while retaining the sediment-water interface and floc layer.

Fibreglass sediment traps based on the Aberdeen design (PAYNE & DAVIES, 1978) were suspended at three depths: 30 m, 85 m, and 145 m which was 5 m off the bottom. The traps were conical with built in buoyancy, and fins for stability. The traps were secured to a 8 mm diameter 3 strand polypropylene rope, held taut between a subsurface buoy at 10-20 m depth and a 250 kg clump of iron chain. A 30 m length of pick-up rope was attached to the sub-surface buoy with a marker buoy at the end. Connections within the assembly were provided by stainless steel shackles and hard eyes. Although bacterial degradation of collected material in situ may cause loss of total weight, and organic C, N and P, no preservative was added to the collection jars (HÅKANSON *et al.*, 1989). This is because the presence of biological poisons may kill zooplankton which swim into the traps, as opposed to zooplankton that die above the traps and fall into them, thus altering the collected material (LEE *et al.*, 1988). It is estimated that 10% of organic material may be lost bi-weekly (BLOESCH & BURNS, 1980), so short redeployment times are ideal, however the monthly servicing employed in this study was considered sufficient.

In February 1991 the traps broke free from their mooring and were lost. A sonar search of the basin, several trawls of the water column and sediment surface and a search of the shores of the loch all failed to locate the traps. However the marker buoy, the subsurface buoys and the topmost trap only were found by a local fisherman washed up on the island of Lismore, outside the entrance of the loch and recovered. It seems likely that too high a strain was placed on the rope by too many subsurface buoys, while the rope was of a design that can fray, and thus the whole assembly came away from the weight, and subsequently, while free, the rope connecting the first and second traps also broke. Three new polypropelene traps, 85 cm long with a 30 cm diameter mouth, and metal frame for strength were prepared. They were deployed at 5 m, 60 m and 135 m (5 m off bottom) as before but using a 8 mm nylon mountaineering rope of a design which does not fray, and with substantially less sub-surface buoyancy at 2 m. The placement of the topmost trap at 5 m proved to be too shallow, as it was within the photic zone rather than just below it. In two summer months the collection was swamped by zooplankton and mussels respectively. Consequently the trap was redeployed at 20 m with the subsurface buoys at 10 m.

In December 1991 the surface marker buoy was lost or stolen, and although a trawl of the basin retrieved the upper 2 traps, and sub-surface buoys, the bottom trap was lost. The two traps were redeployed at 60 m and 135 m, with connections provided by knots, to enable the rope to be wound onto a drum with no fear of abrasions from the shackles. The metal frames were found to be rusting badly, and it is possible that lumps of Fe oxides may have fallen from the frame of the upper trap into the lower trap during retrieval, contaminating the samples.

A2.2 Sample processing

The sediment cores were subsampled, in air, by extruding vertically with a plunger from below, and cutting into sections using guide lengths of core barrel cut to the required thickness and perspex sheets. The wet sediment was weighed, dried in an oven at 50 ^{o}C for several days, and reweighed to determine the water content.

The dry sediment was ground in a tungsten carbide TEMA disc mill for 50 seconds, stored in clean plastic medical sample bottles and reheated in an oven at 50 °C overnight before any subsamples were taken for analysis.

The sediment trap samples were centrifuged at 2000 rpm for 20 minutes in a MSE Mistral 3000i centrifuge and the supernatant poured off. The sediment was dried in an oven at 50 °C for several days then ground and stored as above. For some of the samples a centrifuge was not available and these were allowed to settle and as much of the supernatant removed as possible. This still left a large, variable, quantity of water in the samples, and hence after drying a large variable quantity of salt.

A2.3 Salt correction

The concentrations of elements in marine sediments have to be corrected for the effect of residual sea-salt remaining in the sediments after drying. The salt acts as a dilutant and secondly as a contributor of those elements in abundance in seawater (Na, Mg, Ca, K, S, Br and Sr). The salt content of the sediment cores was calculated from the weight % water content assuming a salinity of 27.3 ‰, using the following equation:

$$\text{salt content} = (2.73 \times W) \div (100 - W)$$

The salt content of the sediment trap samples was determined by slurrying 0.05 g of sample with 100 ml of ultra-pure water, leaving the solution overnight, and filtering the solution through Sartorius membrane filters to remove the particulates. The Cl^- content of the solution was determined by High Performance Liquid Chromatography (HPLC) on a Waters 712 WISP with a Waters 431 Conductivity Detector. The salt content of the sediment was estimated from the Cl^- content of the solution by:

$$\text{salt content} = Cl^-_{solution}(ppm) \times 1.816754 \div (10 \times 0.05)$$

Individual elements were first corrected for the contribution of salt by:

$$element_{act.}(wt.\%) = element_{meas.}(wt.\%) - X(wt.\%) \times \text{salt cont.}(wt.\%)$$

where for Na, X= 0.306; for Mg, X=0.037; for Ca, X= 0.012; and for K, X= 0.011. For Br and S the correction is:

$$element_{actual}(ppm) = element_{meas.}(ppm) - X(ppm) \times \text{salt cont.}(wt.\%)$$

where for S, X= 258; and for Br, X= 19.

All elements are then corrected for dilution by:

$$element_{salt\text{-}free} = element_{meas.} \times (100/(100\text{-salt content}(wt.\%)))$$

A2.4 Major element analysis

Major element (Si, Al, Fe, Mg, Ca, Na, K, Ti, Mn & P) concentrations were determined by X-ray Fluorescence Spectrometry using a Philips PW 1480 sequential wavelength dispersive X-ray spectrometer (equipped with a PW 1510 sample changer). Fused glass beads were prepared by a method similar to that of NORRISH & HUTTON (1969). Approximately 1 g of sample was accurately weighed (±0.0001 g) into a platinum crucible, and an ultra-pure flux (Spectroflux 105, Johnson Matthey Chemicals Ltd.) was added so that the flux:sample weight ratio was exactly 5:1. The crucible was heated in a muffle furnace at 1100 °C for 20 minutes, allowed to cool and reweighed. Any weight loss was made up with a small amount of additional flux, then the glass was remelted and poured into a disc-shaped graphite mould. An aluminium plunger was used to press the glass into a 1 mm thick disc, which was allowed to cool slowly. The X-ray spectrometer was calibrated using international rock and sediment standards.

A2.5 Trace element analysis

Trace element (Sc, Ba, V, La, Ce, Nd, Cr, Ni, Cu, Zn, Pb, Th, U, Rb, Sr, Y, Zr, Nb, Mo, I, & Br) concentrations were determined by XRF (see **A2.4**) on pressed sediment pellets (diameter 37 mm, weight of sediment used 3 g). International rock and sediment standards were used as well as in-house standards. The precision of the analysis determined on replicate samples from the deep basin of Loch Etive (n=9, C30-32 cm) is shown in table A2.5.1.

element	(± ppm)	(± rel.%)	CSE (rel.%)		element	(± ppm)	(± rel.%)	CSE (rel.%)
Sc	1.34	13.33	2.321		Th	0.82	9.53	0.300
Ba	5.54	1.24	0.890		U	0.99	49.23	0.300
V	2.10	1.68	0.967		Rb	0.63	0.68	0.303
Ce	2.83	2.77	0.721		Sr	1.68	0.68	0.203
Nd	1.75	4.47	0.759		Y	0.62	2.36	0.340
Cr	2.60	3.67	0.730		Zr	1.89	1.22	0.209
Ni	0.92	2.28	0.676		Nb	0.42	3.51	0.362
Cu	0.98	4.09	0.539		Mo	0.18	6.28	0.292
Zn	1.23	0.66	0.357		I	7.04	2.98	0.342
Pb	1.41	1.92	0.270		Br	2.53	0.59	0.290

Due to the large amount of salt present in the sediment trap samples it was impossible to correctly calibrate the XRF for several of the trace elements, including Cu, Pb and Zn, and thus the determined concentrations are unreliable. In an attempt to remove the salt, the samples were washed with ultra pure water, but this removed the clays as well, and then sediment pellets could not be pressed.

A2.6 Carbon/Nitrogen analysis

Organic C and N concentrations were determined on a Carlo Erba NA-1500 (combustion temperature was 1050 °C, the oxidation column was packed with chromium trioxide and silvered cobaltous oxide and the reduction column was

packed with copper wire) elemental analyser, using samples from which the $CaCO_3$ had been removed by acid treatment. About 10mg of sample was weighed into acid-washed polypropylene micro-analysis vials, sulphurous acid (0.6 ml, 6% w/v SO_2 , AnalaR) was added and the sample left overnight for effervesence to cease. After dissolved gases were removed in a vacuum oven, the sample was freeze-dried. The sediment ball formed was then easily removed from the vial, and quantitatively transferred to tin capsules. Standards were prepared by weighing isoturea directly into tin capsules. The precision of the analysis, determined on replicate samples, was found to be ± 1.0 % (1σ, n=3) for C and ± 3.0 % (1σ, n=3) for N. Run to run reproducibility was ensured by running a repeat sample.

The above method was recently compared with those of other laboratories (KING *et al.*, 1995). A marine sediment sample and a sediment trap material sample were analysed for total C and N and organic C, and the results are shown in **Table A2.6.1.** Although Edinburgh's organic C results were higher than the mean of all the laboratories, our N results indicate the loss of some organic C during the process, and this should be considered. Otherwise our results compared favourably with the mean values.

A2.7 ^{210}Pb analysis

^{210}Pb was determined by alpha spectroscopy in sediment samples stored for a year before analysis to allow ^{210}Po to be in secular equilibrium with ^{210}Pb. Sediment (0.20 g) was weighed onto a spatula, transferred to a Teflon beaker, and made wet with ultra pure water. The sediment was digested for 24 hours with 30 ml HNO_3 (conc., AnalaR), 10 ml $HClO_4$ (60%, AnalaR) and 10 ml HF (AnalaR), and then fumed to total dryness. It was found that most samples contained a dusty black residue, which remained even after a further 24 hour digestion, but that if the acids were part fumed off, the lids replaced and the digestion continued, the undigested material disappeared quickly. The residue was taken up with heating in 10 ml dilute HCl (1 M, AnalaR), transferred quantitatively to clean medical sample bottles, and 5 ml hydroxilamine hydrochloride solution (40% w/v, AnalaR) added. Polished silver discs were attached with silica gel to the inside of the lid, the lids replaced and the jars inverted so that the solution came in contact with the disc. Po was auto plated at 30 °C with slight shaking for 2-5 days, then the discs washed, dried and analysed by alpha spectrometry as above (see **A1.3**).

A2.8 Gamma Spectroscopy

Ground sediment samples (3 g) were pressed into 37 mm discs and analysed by gamma spectroscopy (see **A1.5**) as soon as possible after collection to minimise ^{234}Th decay. Standards were prepared by spiking aged deep sediment with standard solutions, drying and pressing.

A3 Pore Water

A3.1 Sample collection and processing

A 10cm diameter sediment core was collected using a slow-gravity corer as above, except that the conditions were not very calm, and there was some disturbance of the surface sediment. To prevent the oxidation of the sediment altering the chemistry of the pore water it is necessary to perform all operations in an oxygen-free environment. However a glove-box with a hole to insert the core was not available, so the core was extruded and sliced, as above, in air and each slice was transferred to a plastic bag, the air flushed out with nitrogen gas, and the bag sealed as quickly as possible. It was hoped that the short time that the sediment was exposed to air would be insufficient for significant oxidation to take place. In batches of ten the bags were placed in an oxygen-free Forma Scientific Anaerobic System 1029 glove-box, via an air-lock. The glove box was temperature controlled at 10 °C, which was the temperature of the deep water in the loch. The wet sediment was transferred to centrifuge tubes (cutting the corners from the bags allowed the wet sediment to be squeezed out), which were sealed, removed via the airlock, and centrifuged at 5000 rpm for 30 minutes at 10 °C, in a MSE Europa 24 M centrifuge. The tubes were returned to the glove-box and the pore water drawn off by syringe and filtered through a 1.5 µm pre-filter and a 0.22 µm membrane filter in a disposable Millipore aerosol analysis filter unit. The filtered pore water was acidified with Nitric acid (1 to 1000 v/v, Aristar) and stored in clean medical sample bottles at 4 °C until analysis.

A3.2 Nutrient analysis

Dissolved phosphate was analysed by standard wet-chemical spectrophotometric methods reported in STRICKLAND AND PARSONS (1968), altered for small volumes. Poor spectrophotometric cell quality led to poor precision, with a precision determined on sample F21 of ± 50.0 % (1σ, n=4), which explains the jagged variability of the resultant profile. A second analysis was not carried out due to low volumes of sample available.

A3.3 Manganese and Iron analysis

Dissolved Mn and Fe concentrations were determined by flame AAS as above (see **A1.3**) using standards made up in Loch Etive deep water.

A3.4 ^{210}Pb analysis

Volumes of pore water were combined so that there was enough ^{210}Po on the disc to measure, the pore water spiked with ^{208}Po to measure plating efficiency, and 5ml hydroxilamine hydrochloride (40% w/v, AnalaR), 5 ml sodium citrate (20% w/v, AnalaR) and 1 ml $BiNO_3$ (1% w/v, AnalaR) solutions added. Then ^{210}Po was auto plated and analysed as above (see **A1.3**). Count times of 1-2 weeks were needed.

Appendix B: Results

1. Core A: Deep Station 22nd May 1991
    - 1.1. Major elements and porosity
    - 1.2. Major elements ratioed to Al
    - 1.3. Trace elements
    - 1.4. Trace elements ratioed to Al

2. Core B: Aird's Bay 14th November 1991
    - 2.1. Major elements and porosity
    - 2.2. Major elements ratioed to Al
    - 2.3. Trace elements
    - 2.4. Trace elements ratioed to Al

3. Core C: Deep Station 22nd May 1991
    - 3.1. Major elements and porosity
    - 3.2. Major elements ratioed to Al
    - 3.3. Trace elements
    - 3.4. Trace elements ratioed to Al

4. Transect Cores 23rd-26th March 1992
    - 4.1. Major elements and porosity
    - 4.2. Major elements ratioed to Al
    - 4.3. Trace elements
    - 4.4. Trace elements ratioed to Al

5. Sediment Traps 1990-1992
    - 5.1. Major elements and total mass
    - 5.2. Major elements ratioed to Al
    - 5.3. Major element fluxes
    - 5.4. Trace elements
    - 5.5. Trace elements ratioed to Al
    - 5.6. Trace element fluxes
    - 5.7. Radionuclide data

6. Water Samples
    - 6.1. CTD Results
    - 6.2. Nutrients and dissolved oxygen
    - 6.3. Monthly rainfall
    - 6.4. Weekly rainfall and run-off
    - 6.5. $^{210}Pb/^{210}Po$

7. Pore Water: Core F: Deep Station 18th January 1993
    - 7.1. Nutrients, Manganese, Iron and ^{210}Pb

8. Radionuclide Results
    - 8.1. Long cores
    - 8.2. Transect cores
    - 8.3. Sediment traps

B1.1. CORE A: DEEP STATION 22/5/91

Major elements (salt-free)

Depth Interval (cm)	Si (wt.%)	Al (wt.%)	Fe (wt.%)	Mg (wt.%)	Ca (wt.%)	Na (wt.%)	K (wt.%)	Ti (wt.%)	Mn (wt.%)	P (wt.%)	org-C (wt.%)	N (wt.%)	C/N Ratio	Salt Content (wt.%)	Porosity (vol.%)	Fe/Mn Ratio
0.0-0.5	20.95	6.66	5.43	1.69	1.06	1.92	1.65	0.38	1.51	0.23	6.82	0.53	10.9	16.58	93.9	3.6
0.5-1.0	21.51	6.82	5.49	1.72	1.05	1.98	1.64	0.38	1.02	0.24	ND	ND	ND	14.45	93.1	5.4
1.0-1.5	22.29	6.97	5.40	1.74	1.09	1.94	1.78	0.40	0.54	0.21	6.42	0.49	11.2	12.60	92.2	10.0
1.5-2.0	22.75	7.20	5.31	1.81	1.17	1.94	1.85	0.41	0.44	0.18	ND	ND	ND	11.94	91.8	12.2
2-3	22.71	7.33	5.33	1.82	1.13	2.01	1.95	0.42	0.36	0.16	6.86	0.52	11.2	10.77	91.0	14.8
3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.93	90.3	ND
4-5	23.60	7.52	5.19	1.96	1.19	2.55	1.92	0.42	0.26	0.16	6.54	0.47	12.0	9.49	89.9	19.9
5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.83	90.2	ND
6-7	23.01	7.25	5.14	1.85	1.14	2.27	1.92	0.42	0.23	0.15	6.14	0.44	12.0	9.30	89.7	22.5
7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.12	89.5	ND
8-9	24.31	7.80	5.05	1.99	1.04	2.64	1.88	0.43	0.21	0.14	5.69	0.40	12.2	9.33	89.7	24.2
9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.95	89.3	ND
10-12	23.34	7.48	5.00	1.79	1.02	2.98	2.10	0.43	0.21	0.14	6.02	0.41	12.6	8.06	88.3	23.7
12-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.85	88.0	ND
14-16	24.50	7.84	5.26	2.02	1.13	2.53	2.04	0.45	0.25	0.15	5.92	0.42	12.1	8.03	88.2	21.2
16-18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.45	87.4	ND
18-20	23.43	7.49	4.99	1.88	1.10	2.44	2.06	0.45	0.20	0.14	5.69	0.40	12.3	7.34	87.3	24.6
20-22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.62	87.7	ND
22-24	24.26	7.77	4.96	1.96	1.12	2.54	2.10	0.45	0.19	0.14	5.85	0.41	12.2	7.31	87.2	26.3
24-26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.99	86.7	ND
26-28	25.44	8.33	5.05	2.13	1.18	2.88	2.13	0.45	0.20	0.14	6.02	0.40	12.8	6.77	86.3	25.6
28-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.30	87.2	ND
30-32	24.50	8.04	5.21	2.07	1.08	2.68	2.08	0.45	0.19	0.14	6.16	0.41	13.0	7.42	87.4	27.4
32-34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.29	87.2	ND
34-36	23.90	7.76	5.16	1.94	1.19	2.47	2.10	0.47	0.20	0.13	6.57	0.41	13.6	7.09	86.9	25.5
36-38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.75	86.3	ND
38-40	23.67	7.61	5.14	1.93	1.18	2.56	2.01	0.46	0.22	0.13	6.39	0.39	13.9	6.81	86.4	23.3

ND not determined

B1.2. CORE A: DEEP STATION 22/5/91
Major elements (salt-free) ratioed to Al

Depth Interval (cm)	Si/Al	Fe/Al	Mg/Al	Ca/Al	Na/Al	K/Al	Ti/Al	Mn/Al	P/Al	C/Al	N/Al
0.0-0.5	3.15	0.82	0.25	0.16	0.29	0.25	0.06	0.23	0.035	1.02	0.080
0.5-1.0	3.15	0.81	0.25	0.15	0.29	0.24	0.06	0.15	0.034	ND	ND
1.0-1.5	3.20	0.78	0.25	0.16	0.28	0.26	0.06	0.08	0.029	0.92	0.070
1.5-2.0	3.16	0.74	0.25	0.16	0.27	0.26	0.06	0.06	0.025	ND	ND
2-3	3.10	0.73	0.25	0.15	0.27	0.27	0.06	0.05	0.022	0.94	0.072
3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-5	3.14	0.69	0.26	0.16	0.34	0.26	0.06	0.03	0.021	0.87	0.062
5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6-7	3.17	0.71	0.26	0.16	0.31	0.26	0.06	0.03	0.021	0.85	0.061
7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8-9	3.11	0.65	0.25	0.13	0.34	0.24	0.05	0.03	0.018	0.73	0.051
9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10-12	3.12	0.67	0.24	0.14	0.40	0.28	0.06	0.03	0.019	0.80	0.055
12-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14-16	3.12	0.67	0.26	0.14	0.32	0.26	0.06	0.03	0.019	0.75	0.054
16-18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18-20	3.13	0.67	0.25	0.15	0.33	0.28	0.06	0.03	0.018	0.76	0.053
20-22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22-24	3.12	0.64	0.25	0.14	0.33	0.27	0.06	0.02	0.018	0.75	0.053
24-26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26-28	3.05	0.61	0.26	0.14	0.35	0.26	0.05	0.02	0.017	0.72	0.048
28-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30-32	3.05	0.65	0.26	0.13	0.33	0.26	0.06	0.02	0.017	0.77	0.051
32-34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
34-36	3.08	0.66	0.25	0.15	0.32	0.27	0.06	0.03	0.017	0.85	0.053
36-38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
38-40	3.11	0.68	0.25	0.15	0.34	0.26	0.06	0.03	0.017	0.84	0.052
means											

ND not determined

B1.3. CORE A: DEEP STATION 22/5/91

Trace elements (salt-free)

Depth Interval (cm)	Sc (ppm)	Ba (ppm)	V (ppm)	La (ppm)	Ce (ppm)	Nd (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Th (ppm)	U (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Mo (ppm)	I (ppm)	Br (ppm)
0.0-0.5	10.3	382	122.0	41.8	83.1	32.2	71.2	36.4	5.5	240	120.1	8.5	4.8	102.0	319	23.3	142	11.0	8.9	564	272
0.5-1.0	10.2	378	127.3	48.2	84.4	33.4	75.7	37.4	8.7	238	95.9	7.5	4.9	100.6	308	23.3	151	12.3	7.8	496	261
1.0-1.5	12.5	408	137.6	54.7	98.1	38.4	73.9	36.8	11.1	246	96.9	8.5	5.4	102.1	287	24.6	154	11.3	3.9	419	257
1.5-2.0	12.4	405	142.2	52.0	98.2	40.0	86.8	40.5	14.9	253	96.9	8.6	4.8	100.6	277	25.1	153	12.3	3.6	392	256
2-3	13.2	418	137.5	49.1	102.0	41.2	74.6	38.9	16.8	252	98.4	9.2	5.2	101.5	270	25.3	150	12.4	2.2	369	263
3-4	10.1	434	137.5	54.3	106.8	42.3	77.2	40.6	16.7	241	96.6	8.1	3.0	99.0	269	25.4	170	12.2	1.8	335	235
4-5	11.3	427	133.4	53.6	106.6	39.1	73.4	40.8	18.1	239	93.4	11.0	4.9	101.8	272	24.7	155	12.5	2.1	319	248
5-6	13.6	432	133.9	49.1	94.9	38.1	74.6	39.6	17.4	239	90.2	10.2	2.7	101.5	269	26.2	167	12.9	2.2	306	237
6-7	12.2	412	128.2	55.6	94.4	36.9	77.3	39.1	17.0	239	92.1	9.2	5.8	100.4	270	26.1	170	12.5	2.9	309	245
7-8	13.3	420	133.0	49.8	102.0	39.6	77.9	39.6	16.9	235	89.5	10.1	3.9	100.7	271	25.6	170	12.1	3.1	284	230
8-9	15.2	436	137.2	54.0	103.2	40.4	77.2	39.2	17.8	233	89.8	11.1	4.1	102.0	274	26.0	174	12.5	3.9	291	226
9-10	12.0	425	131.9	49.9	106.9	39.4	76.8	38.1	16.0	230	87.9	10.4	2.9	102.5	273	26.6	174	12.0	2.7	282	225
10-12	9.7	422	139.6	53.4	108.1	44.4	80.3	40.2	17.8	228	89.8	8.8	3.4	100.6	270	26.3	172	11.9	2.2	298	235
12-14	12.0	420	135.6	43.7	96.5	38.5	75.7	37.9	16.0	212	82.4	9.9	4.8	99.3	271	24.6	171	12.2	2.6	277	230
14-16	12.6	433	138.5	50.8	102.1	41.3	78.3	38.3	14.5	213	83.9	10.7	4.3	101.3	277	25.9	177	12.3	2.5	282	225
16-18	15.6	449	135.8	48.3	101.7	38.4	80.0	40.7	16.0	213	83.0	10.0	5.7	101.0	273	25.7	169	12.6	3.1	278	226
18-20	14.6	432	133.4	50.0	104.9	41.2	75.3	39.7	15.4	213	84.4	10.8	4.5	102.1	277	25.7	171	13.1	2.8	274	237
20-22	11.4	419	132.1	55.2	99.8	39.5	75.7	38.1	13.3	212	82.3	10.2	5.3	100.0	276	25.3	175	12.8	2.5	258	228
22-24	13.2	428	136.3	50.2	100.2	36.0	79.3	39.5	17.8	204	82.3	10.2	5.3	101.0	278	26.1	173	12.3	3.3	239	221
24-26	11.9	449	132.9	54.8	92.2	36.3	77.2	37.6	16.6	190	75.8	13.1	5.6	101.3	282	25.3	182	13.5	2.9	238	213
26-28	11.0	447	133.8	47.6	104.3	39.0	81.2	36.6	15.7	196	77.2	10.7	6.0	99.3	285	24.8	172	11.8	2.7	244	221
28-30	16.1	455	133.9	52.8	100.2	38.8	77.6	37.8	15.6	184	72.4	11.5	6.3	101.4	289	26.5	176	12.7	3.9	235	205
30-32	12.6	452	142.0	49.0	105.1	40.5	78.0	39.2	14.7	159	64.9	11.1	8.2	101.5	281	25.4	168	12.6	4.9	215	211
32-34	10.8	496	130.1	48.5	105.2	39.0	71.2	41.6	24.2	143	58.2	10.4	2.4	98.5	289	28.6	184	13.6	6.0	199	270
34-36	8.8	510	130.5	50.0	108.5	38.6	69.1	40.7	20.7	129	51.9	10.5	5.4	96.1	296	27.1	191	13.0	6.3	180	261
36-38	11.9	505	128.4	50.5	102.4	39.9	69.1	38.8	18.2	117	44.4	14.3	4.1	94.3	297	26.9	193	12.8	6.8	169	256
38-40	9.8	514	133.9	49.8	105.5	41.1	68.7	37.6	18.1	110	42.0	9.9	2.4	93.7	301	27.0	185	13.1	7.2	180	260

B1.4. CORE A: DEEP STATION 22/5/91
Trace elements (salt-free) ratioed to Al

Depth Interval (cm)	Sc/Al (x10-4)	Ba/Al (x10-4)	V/Al (x10-4)	La/Al (x10-4)	Ce/Al (x10-4)	Nd/Al (x10-4)	Cr/Al (x10-4)	Ni/AL (x10-4)	Cu/Al (x10-4)	Zn/Al (x10-4)	Pb/Al (x10-4)	Th/Al (x10-4)	U/Al (x10-4)	Rb/Al (x10-4)	Sr/Al (x10-4)	Y/Al (x10-4)	Zr/Al (x10-4)	Nb/Al (x10-4)	Mo/Al (x10-4)	I/Al (x10-4)	Br/Al (x10-4)
0.0-0.5	1.5	57.4	18.3	6.3	12.5	4.8	10.7	5.5	0.8	36.1	18.0	1.3	0.7	15.3	47.9	3.5	21.3	1.7	1.3	84.7	40.8
0.5-1.0	1.5	55.5	18.7	7.1	12.4	4.9	11.1	5.5	1.3	34.9	14.1	1.1	0.7	14.8	45.2	3.4	22.2	1.8	1.1	72.7	38.3
1.0-1.5	1.8	58.5	19.7	7.8	14.1	5.5	10.6	5.3	1.6	35.2	13.9	1.2	0.8	14.6	41.1	3.5	22.1	1.6	0.6	60.1	36.9
1.5-2.0	1.7	56.2	19.7	7.2	13.6	5.6	12.0	5.6	2.1	35.2	13.5	1.2	0.7	14.0	38.5	3.5	21.2	1.7	0.5	54.4	35.5
2-3	1.8	57.0	18.8	6.7	13.9	5.6	10.2	5.3	2.3	34.3	13.4	1.3	0.7	13.8	36.8	3.5	20.5	1.7	0.3	50.3	35.9
3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-5	1.5	56.8	17.7	7.1	14.2	5.2	9.8	5.4	2.4	31.8	12.4	1.5	0.6	13.5	36.2	3.3	20.6	1.7	0.3	42.4	32.9
5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6-7	1.7	56.8	17.7	7.7	13.0	5.1	10.7	5.4	2.3	32.9	12.7	1.3	0.8	13.8	37.3	3.6	23.5	1.7	0.4	42.6	33.7
7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8-9	2.0	55.9	17.6	6.9	13.2	5.2	9.9	5.0	2.3	29.9	11.5	1.4	0.5	13.1	35.1	3.3	22.2	1.6	0.5	37.4	29.0
9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10-12	1.3	56.4	18.6	7.1	14.4	5.9	10.7	5.4	2.4	30.4	12.0	1.2	0.5	13.4	36.0	3.5	23.0	1.6	0.3	39.9	31.5
12-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14-16	1.6	55.1	17.7	6.5	13.0	5.3	10.0	4.9	1.8	27.2	10.7	1.4	0.6	12.9	35.3	3.3	22.6	1.6	0.3	35.9	28.7
16-18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18-20	1.9	57.7	17.8	6.7	14.0	5.5	10.1	5.3	2.1	28.5	11.3	1.4	0.6	13.6	36.9	3.4	22.8	1.7	0.4	36.6	31.6
20-22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22-24	1.7	55.1	17.5	6.5	12.9	4.6	10.2	5.1	2.3	26.3	10.6	1.3	0.7	13.0	35.8	3.4	22.3	1.6	0.4	30.8	28.5
24-26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26-28	1.3	53.6	16.1	5.7	12.5	4.7	9.7	4.4	1.9	23.5	9.3	1.3	0.7	11.9	34.2	3.0	20.7	1.4	0.3	29.3	26.5
28-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30-32	1.6	56.2	17.7	6.1	13.1	5.0	9.7	4.9	1.8	19.8	8.1	1.4	1.0	12.6	35.0	3.2	20.9	1.6	0.6	26.8	26.2
32-34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
34-36	1.1	65.6	16.8	6.4	14.0	5.0	8.9	5.2	2.7	16.6	6.7	1.4	0.7	12.4	38.1	3.5	24.6	1.7	0.8	23.2	33.6
36-38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
38-40	1.3	67.5	17.6	6.5	13.9	5.4	9.0	4.9	2.4	14.5	5.5	1.3	0.3	12.3	39.5	3.6	24.3	1.7	0.9	23.7	34.1

ND not determined

B2.1. CORE B: AIRD'S BAY 14/11/91

Depth Interval (cm)	Major elements (salt-free) Si (wt.%)	Al (wt.%)	Fe (wt.%)	Mg (wt.%)	Ca (wt.%)	Na (wt.%)	K (wt.%)	Ti (wt.%)	Mn (wt.%)	P (wt.%)	org-C (wt.%)	N (wt.%)	C/N Ratio	Salt Content (wt.%)	Porosity (%)	Fe/Mn Ratio
0.0-0.5	24.4	6.91	5.18	1.69	1.34	1.84	1.83	0.412	0.136	0.247	5.61	0.50	9.5	10.89	91.0	38.0
0.5-1.0	25.0	7.10	5.11	1.76	1.28	1.90	1.85	0.411	0.125	0.252	ND	ND	ND	9.21	89.6	40.7
1.0-1.5	24.8	7.09	5.34	1.74	1.25	1.69	1.88	0.420	0.100	0.249	5.47	0.50	9.3	8.58	88.9	53.4
1.5-2.0	24.7	7.02	5.22	1.68	1.22	1.61	1.90	0.426	0.083	0.231	ND	ND	ND	8.05	88.3	63.2
2-3	24.6	6.92	4.88	1.65	1.32	1.53	1.89	0.422	0.067	0.186	5.21	0.49	9.2	7.54	87.6	72.8
3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.09	86.9	ND
4-5	24.7	7.24	5.01	1.72	1.34	1.68	2.03	0.442	0.052	0.148	5.47	0.47	10.1	6.87	86.5	95.6
5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.49	85.8	ND
6-7	24.9	7.29	4.92	1.72	1.18	1.66	2.07	0.447	0.049	0.136	5.63	0.45	10.7	6.32	85.5	100.9
7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.47	85.8	ND
8-9	26.1	7.64	5.00	1.82	1.17	1.81	2.04	0.442	0.052	0.130	5.07	0.41	10.6	6.90	86.6	96.9
9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.74	86.3	ND
10-12	25.1	7.59	4.99	1.84	1.17	1.79	2.10	0.442	0.049	0.127	4.93	0.43	9.8	6.61	86.1	101.9
12-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.42	85.7	ND
14-16	25.6	7.65	4.93	1.84	1.04	1.78	2.14	0.454	0.050	0.120	4.67	0.41	9.7	5.78	84.4	98.3
16-18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.99	84.8	ND
18-20	25.2	7.75	4.86	1.81	0.97	2.33	2.25	0.451	0.047	0.116	4.81	0.43	9.6	6.10	85.1	103.3
20-22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.60	86.0	ND
22-24	24.2	7.53	5.24	1.76	1.37	1.62	2.13	0.440	0.061	0.113	4.95	0.42	10.0	7.02	86.8	86.2
24-26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.06	86.8	ND
26-28	25.0	7.50	4.79	1.73	1.32	1.60	2.13	0.446	0.066	0.108	4.74	0.41	9.9	6.98	86.7	72.8
28-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.69	86.2	ND
30-32	25.2	8.19	4.91	2.03	1.49	1.85	2.19	0.457	0.063	0.112	4.76	0.42	9.8	7.21	87.1	77.5
32-34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.08	86.9	ND
34-46	24.4	8.40	4.89	1.87	1.61	1.69	2.24	0.458	0.056	0.110	5.26	0.40	11.4	6.79	86.4	87.9
36-38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.66	86.1	ND
38-40	24.8	8.24	4.87	1.86	1.05	1.74	2.30	0.476	0.052	0.108	4.90	0.39	10.7	6.50	85.9	93.3
40-42	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.29	85.4	ND
42-44	25.0	8.30	4.74	1.84	1.05	1.68	2.30	0.483	0.051	0.108	5.04	ND	ND	6.35	85.6	92.4
44-46	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.26	85.4	ND
46-48	24.8	7.77	4.73	1.81	1.21	1.64	2.26	0.471	0.052	0.107	4.92	0.40	10.6	6.21	85.3	90.9
48-50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.08	85.0	ND
50-52	25.2	8.19	4.82	1.93	1.11	1.88	2.29	0.471	0.045	0.112	5.35	0.44	10.5	6.31	85.5	107.9
52-54	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.25	85.4	ND

ND not determined

B2.2. CORE B: AIRD'S BAY 14/11/91
Trace elements (salt-free) ratioed to Al

Depth Interval (cm)	Si/Al	Fe/Al	Mg/Al	Ca/Al	Na/Al	K/Al	Ti/Al	Mn/Al	P/Al	C/Al	N/Al
0.0-0.5	3.5	0.75	0.25	0.19	0.27	0.26	0.060	0.0198	0.036	0.81	0.073
0.5-1.0	3.5	0.72	0.25	0.18	0.27	0.26	0.058	0.0177	0.036	ND	ND
1.0-1.5	3.5	0.75	0.25	0.18	0.24	0.27	0.059	0.0141	0.035	0.77	0.071
1.5-2.0	3.5	0.74	0.24	0.17	0.23	0.27	0.061	0.0118	0.033	ND	ND
2-3	3.5	0.71	0.24	0.19	0.22	0.27	0.061	0.0097	0.027	0.75	0.070
3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-5	3.4	0.69	0.24	0.18	0.23	0.28	0.061	0.0072	0.020	0.76	0.064
5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6-7	3.4	0.67	0.24	0.16	0.23	0.28	0.061	0.0067	0.019	0.77	0.062
7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8-9	3.4	0.65	0.24	0.15	0.24	0.27	0.058	0.0068	0.017	0.66	0.054
9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10-12	3.3	0.66	0.24	0.15	0.24	0.28	0.058	0.0064	0.017	0.65	0.057
12-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14-16	3.4	0.64	0.24	0.14	0.23	0.28	0.059	0.0066	0.016	0.61	0.054
16-18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18-20	3.3	0.63	0.23	0.13	0.30	0.29	0.058	0.0061	0.015	0.62	0.055
20-22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22-24	3.2	0.70	0.23	0.18	0.22	0.28	0.058	0.0081	0.015	0.66	0.056
24-26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26-28	3.3	0.64	0.23	0.18	0.21	0.28	0.059	0.0088	0.014	0.63	0.055
28-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30-32	3.1	0.60	0.25	0.18	0.23	0.27	0.056	0.0077	0.014	0.58	0.051
32-34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
34-46	2.9	0.58	0.22	0.19	0.20	0.27	0.055	0.0066	0.013	0.63	0.047
36-38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
38-40	3.0	0.59	0.23	0.13	0.21	0.28	0.058	0.0063	0.013	0.59	0.047
40-42	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
42-44	3.0	0.57	0.22	0.13	0.20	0.28	0.058	0.0062	0.013	0.61	ND
44-46	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
46-48	3.2	0.61	0.23	0.16	0.21	0.29	0.061	0.0067	0.014	0.63	0.051
48-50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
50-52	3.1	0.59	0.24	0.14	0.23	0.28	0.057	0.0054	0.014	0.65	0.053
52-54	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND not determined

B2.3. CORE B: AIRD'S BAY 14/11/91

Trace elements (salt-free)

Depth Interval (cm)	Sc (ppm)	Ba (ppm)	V (ppm)	La (ppm)	Ce (ppm)	Nd (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Th (ppm)	U (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Mo (ppm)	I (ppm)	Br (ppm)
0.0-0.5	11.0	380	112	46.2	87.4	32.9	80.6	36.5	12.5	213	87.6	7.6	3.8	103.5	267	22.7	176	13.4	2.1	494	338
0.5-1.0	10.2	409	129	47.3	90.7	37.9	84.5	39.9	17.5	210	97.9	2.3	5.8	101.7	257	23.9	172	11.9	2.8	471	334
1.0-1.5	13.1	389	125	46.8	95.7	34.9	80.9	39.5	18.3	215	89.3	6.7	2.3	102.3	252	24.3	180	11.9	2.0	431	333
1.5-2.0	13.4	402	121	44.7	94.3	37.4	84.4	39.5	17.0	215	86.7	7.2	2.9	103.5	247	24.0	178	12.4	2.1	408	328
2-3	11.8	408	120	44.7	100.6	39.4	84.9	37.6	18.1	218	91.5	9.4	3.6	105.6	247	23.9	187	12.0	1.5	373	320
3-4	16.1	415	126	50.0	96.5	39.5	85.5	39.0	19.3	228	94.4	9.4	4.1	106.1	251	24.3	191	12.4	1.5	370	318
4-5	11.5	422	133	48.5	88.3	34.0	88.5	40.9	21.4	233	99.1	9.2	3.1	107.3	236	25.0	182	12.0	1.3	340	319
5-6	11.1	416	129	47.4	96.2	34.8	87.6	42.6	22.1	231	98.3	7.2	4.3	104.3	275	24.7	174	12.7	1.6	325	312
6-7	17.0	426	136	48.3	94.7	40.6	96.2	42.2	22.0	240	98.6	11.2	4.4	108.6	226	25.4	182	14.4	1.6	330	315
7-8	16.0	416	132	48.5	96.4	38.8	90.0	42.1	21.4	233	93.3	10.2	4.1	105.8	228	25.1	185	13.2	2.2	299	288
8-9	12.9	417	128	46.9	89.9	40.8	89.7	41.4	20.9	237	94.5	9.2	3.3	107.0	226	25.9	190	12.6	2.1	287	279
9-10	14.8	415	127	44.5	105.7	42.6	91.7	40.6	21.0	240	96.0	9.5	5.4	108.9	239	24.2	184	12.9	2.7	291	277
10-12	14.6	415	131	48.3	94.1	39.1	91.7	43.9	19.8	247	97.7	9.7	4.9	110.1	227	25.9	178	12.8	3.5	295	286
12-14	11.1	421	135	47.0	105.4	46.4	96.3	40.6	22.2	247	97.6	9.5	4.2	109.7	224	26.1	180	13.4	3.5	279	276
14-16	16.5	434	133	52.6	102.0	42.5	94.6	41.1	22.9	237	91.8	7.6	3.7	107.5	221	24.6	186	12.7	2.7	251	263
16-18	14.3	436	131	46.6	97.8	36.2	94.8	43.8	23.6	239	90.6	9.0	4.0	108.5	230	25.6	188	13.2	2.6	250	259
18-20	12.8	426	131	44.9	100.6	38.7	93.9	42.2	19.6	237	92.0	9.7	4.5	109.4	223	25.5	190	13.3	2.7	243	262
20-22	15.5	405	127	48.1	93.5	35.1	94.5	43.5	18.6	237	92.7	9.0	3.1	110.1	231	25.5	173	12.6	4.0	258	268
22-24	12.2	411	125	46.1	95.8	38.6	92.4	41.5	18.5	230	92.6	10.2	4.4	110.5	236	23.6	174	13.4	4.9	250	266
24-26	13.2	414	121	41.6	97.8	38.8	89.6	40.8	16.6	211	86.4	10.3	6.7	110.4	235	23.7	173	13.8	5.4	223	255
26-28	16.3	418	121	44.8	105.5	40.4	93.4	41.4	16.8	195	81.3	10.3	3.3	110.0	237	24.4	177	13.3	4.0	207	245
28-30	14.3	424	120	45.2	97.8	36.8	91.5	39.5	15.3	179	71.6	8.4	4.0	111.5	258	25.0	168	12.9	5.0	203	247
30-32	15.1	428	118	48.2	92.8	37.7	91.3	40.3	15.1	168	65.0	9.6	4.2	113.5	249	25.0	162	13.6	3.7	203	262
32-34	12.8	436	125	53.3	96.0	38.0	93.0	42.2	15.1	164	63.2	9.9	7.7	116.7	237	24.3	168	14.1	4.5	202	264
34-46	14.4	417	127	47.2	99.2	43.9	94.9	41.2	15.1	147	56.6	10.9	3.9	113.8	259	25.3	161	13.1	6.4	203	248
36-38	13.5	433	124	51.0	96.4	38.5	94.7	42.9	13.2	132	49.0	12.6	1.4	113.8	234	24.9	169	14.1	5.7	190	238
38-40	14.2	453	122	49.6	98.2	39.5	93.5	41.8	15.4	129	49.2	9.4	5.7	115.4	234	25.8	171	13.7	4.1	184	242
40-42	12.7	434	120	42.8	102.2	40.7	94.7	41.0	13.6	122	47.1	11.1	4.7	111.7	236	24.5	173	13.1	3.5	181	241
42-44	13.9	456	121	48.1	103.7	40.8	94.2	41.1	14.3	122	46.7	11.0	3.6	113.7	235	25.6	171	13.7	2.3	180	235
44-46	14.6	448	124	47.3	99.7	37.7	92.1	42.0	14.0	123	43.7	10.8	5.7	112.7	244	25.2	171	14.0	2.9	178	234
46-48	12.9	434	122	48.9	98.1	39.9	93.0	40.0	14.5	121	44.7	11.2	4.8	113.0	242	25.4	168	13.1	2.8	185	234
48-50	18.1	429	125	46.2	100.3	37.8	92.4	41.0	14.6	114	44.2	9.2	6.3	109.9	274	24.0	163	13.0	3.6	170	227
50-52	15.2	450	126	50.3	102.7	39.8	94.4	40.8	12.3	116	43.7	10.7	4.8	113.8	244	26.5	172	13.6	4.7	186	245
52-54	16.4	455	125	46.5	100.9	43.8	94.9	43.7	12.3	115	43.1	9.9	7.7	116.2	240	25.4	168	13.5	3.9	178	243

B2.4. CORE B: AIRD'S BAY 14/11/91

Trace elements (salt-free\ ratioed to Al

Depth Interval (cm)	Sc/Al (x10-4)	Ba/Al (x10-4)	V/Al (x10-4)	La/Al (x10-4)	Ce/Al (x10-4)	Nd/Al (x10-4)	Cr/Al (x10-4)	Ni/Al (x10-4)	Cu/Al (x10-4)	Zn/Al (x10-4)	Pb/Al (x10-4)	Th/Al (x10-4)	U/Al (x10-4)	Rb/Al (x10-4)	Sr/Al (x10-4)	Y/al (x10-4)	Zr/Al (x10-4)	Nb/Al (x10-4)	Mo/Al (x10-4)	I/Al (x10-4)	Br/Al (x10-4)
0.0-0.5	1.59	55.0	16.18	6.69	12.66	4.76	11.66	5.28	1.80	30.8	12.69	1.10	0.55	14.98	38.7	3.28	25.5	1.93	0.31	71.5	48.9
0.5-1.0	1.44	57.6	18.13	6.65	12.77	5.34	11.90	5.62	2.47	29.6	13.79	0.33	0.82	14.32	36.2	3.37	24.3	1.68	0.39	66.4	47.1
1.0-1.5	1.85	54.8	17.61	6.61	13.51	4.92	11.42	5.57	2.58	30.3	12.60	0.94	0.32	14.43	35.6	3.43	25.4	1.68	0.28	60.8	47.0
1.5-2.0	1.90	57.3	17.18	6.37	13.43	5.33	12.02	5.62	2.42	30.6	12.34	1.02	0.42	14.74	35.1	3.42	25.3	1.77	0.29	58.1	46.6
2-3	1.70	58.9	17.41	6.45	14.53	5.69	12.27	5.44	2.61	31.5	13.22	1.36	0.52	15.25	35.7	3.45	27.1	1.73	0.22	53.8	46.3
3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-5	1.59	58.2	18.42	6.70	12.19	4.70	12.22	5.65	2.95	32.2	13.69	1.28	0.43	14.82	32.6	3.46	25.2	1.66	0.18	46.9	44.1
5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6-7	2.33	58.4	18.70	6.62	12.98	5.56	13.19	5.78	3.01	32.9	13.52	1.54	0.60	14.88	30.9	3.48	24.9	1.98	0.22	45.3	43.2
7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8-9	1.69	54.6	16.83	6.15	11.78	5.35	11.75	5.42	2.74	31.0	12.38	1.21	0.44	14.01	29.6	3.39	24.9	1.65	0.28	37.6	36.5
9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10-12	1.92	54.7	17.29	6.36	12.39	5.15	12.07	5.78	2.61	32.5	12.86	1.28	0.65	14.50	29.9	3.41	23.4	1.69	0.47	38.9	37.7
12-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14-16	2.15	56.8	17.34	6.88	13.33	5.55	12.36	5.37	3.00	31.0	12.00	1.00	0.49	14.05	28.9	3.22	24.3	1.66	0.35	32.8	34.4
16-18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18-20	1.65	55.0	16.85	5.80	12.99	4.99	12.12	5.44	2.53	30.6	11.87	1.25	0.58	14.11	28.8	3.28	24.5	1.72	0.34	31.4	33.8
20-22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22-24	1.61	54.6	16.65	6.13	12.72	5.13	12.27	5.51	2.46	30.6	12.30	1.36	0.59	14.67	31.3	3.13	23.2	1.79	0.66	33.2	35.4
24-26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26-28	2.18	55.7	16.08	5.98	14.06	5.39	12.46	5.52	2.24	26.0	10.84	1.38	0.44	14.67	31.7	3.25	23.6	1.78	0.53	27.7	32.7
28-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30-32	1.84	52.2	14.46	5.88	11.33	4.61	11.14	4.92	1.84	20.5	7.93	1.17	0.51	13.85	30.4	3.05	19.8	1.66	0.45	24.8	31.9
32-34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
34-46	1.71	49.7	15.07	5.62	11.82	5.22	11.31	4.91	1.80	17.5	6.75	1.30	0.46	13.55	30.8	3.01	19.1	1.56	0.77	24.2	29.5
36-38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
38-40	1.73	55.0	14.79	6.03	11.92	4.79	11.35	5.08	1.87	15.7	5.97	1.14	0.69	14.01	28.4	3.13	20.8	1.66	0.49	22.4	29.4
40-42	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
42-44	1.67	54.9	14.61	5.79	12.49	4.91	11.34	4.95	1.72	14.7	5.62	1.32	0.44	13.70	28.3	3.09	20.6	1.65	0.28	21.7	28.3
44-46	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
46-48	1.66	55.9	15.71	6.30	12.62	5.13	11.96	5.15	1.87	15.5	5.75	1.44	0.62	14.54	31.1	3.27	21.6	1.69	0.36	23.8	30.2
48-50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
50-52	1.85	54.9	15.35	6.14	12.54	4.86	11.52	4.98	1.50	14.2	5.33	1.30	0.59	13.89	29.8	3.23	21.0	1.65	0.57	22.7	30.0
52-54	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND not determined

B3.1. CORE C: DEEP STATION 14/11/91

Depth Interval (cm)	Major elements (salt-free) Si (wt.%)	Al (wt.%)	Fe (wt.%)	Mg (wt.%)	Ca (wt.%)	Na (wt.%)	K (wt.%)	Ti (wt.%)	Mn (wt.%)	P (wt.%)	org-C (wt.%)	N (wt.%)	C/N ratio	Salt Content (wt.%)	Porosity (vol.%)	Fe/Mn Ratio
0.0-0.5	22.60	7.38	5.23	1.98	1.05	2.43	1.56	0.38	0.90	0.19	6.60	0.50	11.3	15.14	93.4	5.8
0.5-1.0	23.78	7.62	5.16	2.05	1.18	2.25	1.84	0.40	0.67	0.19	ND	ND	ND	12.33	92.0	7.7
1.0-1.5	22.88	7.20	5.50	1.84	1.18	1.74	1.85	0.42	0.64	0.18	6.42	0.49	11.3	11.45	91.4	8.5
1.5-2.0	22.95	7.18	5.54	1.80	1.24	1.72	1.83	0.43	0.55	0.18	ND	ND	ND	11.17	91.2	10.0
2-3	23.15	7.29	5.48	1.83	1.16	1.80	1.84	0.43	0.53	0.17	6.59	0.49	11.6	10.86	91.0	10.4
3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.37	90.6	ND
4-5	23.26	7.27	5.66	1.82	1.15	1.78	1.89	0.43	0.44	0.16	6.13	0.44	11.9	10.25	90.5	12.8
5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.47	90.7	ND
6-7	23.28	7.31	5.48	1.81	1.15	1.62	1.94	0.43	0.45	0.15	6.20	0.46	11.5	10.68	90.9	12.3
7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.40	90.7	ND
8-9	24.13	7.62	5.46	1.95	1.18	2.11	1.93	0.43	0.45	0.15	6.12	0.45	11.6	10.90	91.1	12.0
9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.08	90.4	ND
10-12	23.38	7.28	5.51	1.83	1.13	1.95	1.97	0.43	0.40	0.14	5.86	0.43	11.8	9.67	90.0	13.9
12-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.40	89.8	ND
14-16	23.61	7.33	5.57	1.81	1.10	1.85	1.96	0.43	0.40	0.14	6.04	0.43	12.0	9.29	89.7	13.8
16-18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.98	89.3	ND
18-20	23.75	7.43	5.51	1.76	1.07	1.95	2.06	0.44	0.31	0.14	6.18	0.56	9.4	9.44	89.8	17.8
20-22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.12	89.5	ND
22-24	25.12	7.96	5.42	1.99	1.06	2.32	2.01	0.44	0.29	0.15	6.19	0.55	9.6	9.21	89.6	18.8
24-26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.21	89.6	ND
26-28	23.81	7.59	5.32	1.81	1.05	1.93	2.00	0.44	0.25	0.14	6.53	0.59	9.5	8.72	89.1	21.1
28-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.48	88.8	ND
30-32	24.65	7.99	5.25	2.01	1.06	2.35	2.00	0.44	0.27	0.14	6.56	0.64	8.8	8.61	88.9	19.4
32-34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.92	89.3	ND
34-36	23.44	7.52	5.42	1.81	1.08	1.80	2.04	0.45	0.26	0.13	6.59	0.51	11.0	8.02	88.2	20.6
36-38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.42	88.7	ND
38-40	23.32	7.54	5.36	1.79	1.11	1.81	2.05	0.47	0.28	0.13	6.23	0.50	10.7	9.05	89.4	18.8
40-42	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.42	88.7	ND
42-44	23.23	7.50	5.50	1.81	1.11	2.04	2.07	0.45	0.29	0.13	6.65	0.61	9.4	8.64	89.0	18.9
44-46	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.50	88.8	ND
46-48	23.98	7.85	5.51	1.96	1.08	2.17	2.03	0.45	0.32	0.13	7.05	0.61	9.9	8.14	88.4	17.3
48-50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.16	88.4	ND

ND not determined

B3.2. CORE C: DEEP STATION 14/11/91

Major elements (salt-free) ratioed to Al

Depth Interval (cm)	Si/Al	Fe/Al	Mg/Al	Ca/Al	Na/Al	K/Al	Ti/Al	Mn/Al	P/Al	C/Al	N/Al
0.0-0.5	3.06	0.71	0.27	0.14	0.33	0.21	0.05	0.12	0.03	0.89	0.07
0.5-1.0	3.12	0.68	0.27	0.15	0.30	0.24	0.05	0.09	0.02	ND	ND
1.0-1.5	3.18	0.76	0.26	0.16	0.24	0.26	0.06	0.09	0.02	0.89	0.07
1.5-2.0	3.20	0.77	0.25	0.17	0.24	0.26	0.06	0.08	0.02	ND	ND
2-3	3.18	0.75	0.25	0.16	0.25	0.25	0.06	0.07	0.02	0.90	0.07
3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-5	3.20	0.78	0.25	0.16	0.24	0.26	0.06	0.06	0.02	0.84	0.06
5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6-7	3.19	0.75	0.25	0.16	0.22	0.27	0.06	0.06	0.02	0.85	0.06
7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8-9	3.17	0.72	0.26	0.15	0.28	0.25	0.06	0.06	0.02	0.80	0.06
9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10-12	3.21	0.76	0.25	0.16	0.27	0.27	0.06	0.05	0.02	0.80	0.06
12-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14-16	3.22	0.76	0.25	0.15	0.25	0.27	0.06	0.05	0.02	0.82	0.06
16-18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18-20	3.20	0.74	0.24	0.14	0.26	0.28	0.06	0.04	0.02	0.83	0.08
20-22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22-24	3.15	0.68	0.25	0.13	0.29	0.25	0.06	0.04	0.02	0.78	0.07
24-26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26-28	3.14	0.70	0.24	0.14	0.25	0.26	0.06	0.03	0.02	0.86	0.08
28-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30-32	3.09	0.66	0.25	0.13	0.29	0.25	0.06	0.03	0.02	0.82	0.08
32-34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
34-36	3.12	0.72	0.24	0.14	0.24	0.27	0.06	0.04	0.02	0.88	0.07
36-38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
38-40	3.09	0.71	0.24	0.15	0.24	0.27	0.06	0.04	0.02	0.83	0.07
40-42	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
42-44	3.10	0.73	0.24	0.15	0.27	0.28	0.06	0.04	0.02	0.89	0.08
44-46	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
46-48	3.05	0.70	0.25	0.14	0.28	0.26	0.06	0.04	0.02	0.90	0.08
48-50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND not determined

B3.3. CORE C: DEEP STATION 14/11/91

Depth Interval (cm)	Trace element concentrations (salt-free)																				
	Sc (ppm)	Ba (ppm)	V (ppm)	La (ppm)	Ce (ppm)	Nd (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Th (ppm)	U (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Mo (ppm)	I (ppm)	Br (ppm)
0.0-0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
0.5-1.0	10.4	406	131	44.1	100.6	40.2	72.2	37.1	14.5	241	94.0	9.7	5.2	102.1	287	24.5	154	12.2	3.7	397	235
1.0-1.5	10.2	412	131	50.1	101.4	38.4	73.2	38.3	14.2	243	93.4	9.7	4.5	102.5	284	25.3	156	12.5	2.3	383	240
1.5-2.0	11.8	414	133	54.5	102.0	40.9	74.9	38.8	16.4	238	89.7	8.0	5.6	101.1	281	25.2	160	12.2	2.5	364	232
2-3	13.2	429	135	52.3	97.8	36.9	75.4	37.1	17.4	240	93.1	9.9	4.3	102.3	278	25.0	158	13.1	2.1	349	232
3-4	15.0	410	131	53.4	96.0	36.9	77.5	39.4	15.7	241	92.0	8.6	3.6	100.4	288	26.3	156	12.3	1.9	328	230
4-5	9.7	425	136	53.6	105.7	35.8	78.1	40.0	16.9	241	92.6	9.8	5.8	102.2	271	25.4	160	12.0	1.9	328	234
5-6	11.7	421	138	46.2	99.7	38.6	76.2	39.0	16.3	240	91.9	8.9	5.8	103.1	272	25.5	160	12.4	1.8	322	230
6-7	15.8	412	137	56.3	105.2	37.8	78.7	37.7	18.4	240	90.6	8.8	4.9	102.8	271	25.6	164	12.1	1.5	322	229
7-8	10.5	425	134	52.2	99.8	41.9	74.0	39.2	17.1	240	92.9	8.7	5.2	102.7	270	25.4	159	11.9	1.5	305	222
8-9	14.0	421	136	56.0	97.3	38.2	75.0	39.4	16.8	242	94.1	11.1	2.7	102.5	272	26.0	162	13.2	1.6	301	213
9-10	13.5	395	141	52.8	103.4	39.6	79.3	41.5	19.8	242	92.2	10.6	3.2	102.3	266	25.1	155	11.2	1.8	290	224
10-12	12.7	420	135	54.9	106.4	42.4	75.5	39.6	16.1	241	91.2	8.5	4.5	101.9	266	26.9	161	12.3	2.3	287	220
12-14	14.1	423	141	51.8	102.5	39.8	74.9	40.6	18.3	241	89.9	9.2	5.2	101.1	264	25.7	164	11.8	3.0	280	213
14-16	16.4	424	141	50.5	107.2	40.2	79.6	38.9	19.2	239	93.5	7.4	5.5	101.9	266	26.2	160	13.0	3.0	289	211
16-18	12.3	419	142	58.2	103.4	38.3	77.1	38.5	19.0	240	92.0	8.3	2.4	100.6	262	24.9	156	11.9	2.3	283	221
18-20	12.8	434	142	56.4	107.6	41.4	78.7	40.9	20.2	239	90.7	10.3	2.7	100.9	267	28.5	167	12.5	2.7	275	202
20-22	13.2	426	142	57.3	108.7	41.9	77.8	39.7	19.6	234	90.7	10.3	3.9	102.9	265	26.3	163	12.1	2.5	273	209
22-24	11.7	431	143	52.4	107.6	41.5	81.2	38.2	17.3	228	87.2	10.8	5.2	103.8	269	25.4	165	13.0	2.5	279	209
24-26	15.1	444	144	56.3	102.3	35.6	79.1	39.1	17.6	221	88.8	9.6	5.2	103.0	266	26.5	167	11.9	2.6	265	202
26-28	17.2	435	149	55.2	104.4	41.4	81.9	40.5	18.1	218	86.3	10.3	5.0	104.2	270	26.0	164	12.4	2.6	254	215
28-30	14.1	430	144	56.7	105.2	38.4	81.0	40.3	20.1	214	84.1	10.2	5.5	103.0	267	26.6	158	13.1	2.1	255	216
30-32	12.4	442	146	52.6	110.6	43.4	79.0	39.5	16.0	208	83.2	9.5	5.0	104.1	273	27.0	162	12.8	2.1	255	213
32-34	15.4	460	140	54.1	111.7	40.1	78.0	39.0	15.4	199	80.4	11.1	5.4	105.1	276	25.9	162	12.4	2.7	263	201
34-36	13.5	445	151	57.7	108.1	39.4	80.6	40.4	17.9	185	75.8	12.1	4.8	103.8	276	27.0	166	12.7	3.5	227	202
36-38	12.2	454	149	51.1	101.1	40.6	81.7	39.2	16.4	175	72.1	9.7	3.7	104.0	276	27.0	163	12.7	3.2	235	201
38-40	10.4	463	140	54.6	112.0	39.3	77.4	39.6	14.5	174	70.7	11.5	6.2	103.6	280	26.2	162	12.6	3.4	226	185
40-42	15.5	441	144	54.6	108.8	40.8	80.2	38.3	14.5	161	66.3	12.0	4.7	103.7	276	25.2	161	12.4	4.6	231	202
42-44	13.2	438	138	50.3	105.0	40.3	76.7	37.9	15.4	174	70.5	10.4	2.6	103.7	277	25.6	161	12.5	4.5	224	197
44-46	12.6	458	140	54.9	108.3	38.4	76.5	37.4	14.3	155	63.6	10.8	7.1	101.2	302	24.8	164	12.6	4.6	208	191
46-48	13.2	467	141	52.4	107.9	40.3	77.7	38.1	13.3	131	55.0	10.7	3.2	100.3	288	26.0	166	13.8	3.8	176	191
48-50	9.3	457	134	56.0	104.6	41.2	76.4	37.2	12.8	126	53.9	10.8	3.6	100.5	286	24.8	167	12.2	4.1	172	184

ND not determined

B3.4. CORE C: DEEP STATION 14/11/91

Depth Interval (cm)	Trace elements (salt-free) ratioed to Al																				
	Sc/Al (x10-4)	Ba/Al (x10-4)	V/Al (x10-4)	La/Al (x10-4)	Ce/Al (x10-4)	Nd/Al (x10-4)	Cr/Al (x10-4)	Ni/Al (x10-4)	Cu/Al (x10-4)	Zn/Al (x10-4)	Pb/Al (x10-4)	Th/Al (x10-4)	U/Al (x10-4)	Rb/Al (x10-4)	Sr/Al (x10-4)	Y/Al (x10-4)	Zr/Al (x10-4)	Nb/Al (x10-4)	Mo/Al (x10-4)	I/Al (x10-4)	Br/Al (x10-4)
0.0-0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
0.5-1.0	1.36	53.21	17.13	5.79	13.19	5.27	9.47	4.86	1.90	31.64	12.33	1.27	0.69	13.39	37.68	3.22	20.17	1.60	0.48	52.11	30.83
1.0-1.5	1.41	57.20	18.14	6.96	14.08	5.33	10.16	5.32	1.98	33.71	12.97	1.35	0.63	14.24	39.40	3.51	21.62	1.74	0.31	53.20	33.39
1.5-2.0	1.65	57.61	18.50	7.59	14.21	5.69	10.43	5.41	2.29	33.12	12.50	1.11	0.78	14.08	39.18	3.51	22.30	1.69	0.34	50.69	32.29
2-3	1.82	58.88	18.54	7.18	13.43	5.07	10.35	5.10	2.39	32.88	12.78	1.36	0.59	14.04	38.22	3.43	21.73	1.80	0.29	47.84	31.87
3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-5	1.33	58.38	18.77	7.37	14.54	4.92	10.74	5.50	2.33	33.21	12.73	1.35	0.80	14.05	37.22	3.49	22.05	1.65	0.26	45.10	32.15
5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6-7	2.16	56.45	18.70	7.71	14.40	5.18	10.77	5.16	2.51	32.81	12.40	1.21	0.67	14.07	37.13	3.51	22.46	1.65	0.20	44.01	31.39
7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8-9	1.84	55.27	17.82	7.35	12.78	5.01	9.85	5.17	2.21	31.75	12.35	1.46	0.35	13.46	35.71	3.42	21.31	1.74	0.21	39.56	27.93
9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10-12	1.75	57.70	18.54	7.54	14.61	5.82	10.37	5.44	2.20	33.06	12.53	1.17	0.62	13.98	36.54	3.69	22.13	1.69	0.32	39.46	30.16
12-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14-16	2.24	57.87	19.16	6.88	14.61	5.49	10.85	5.31	2.62	32.65	12.75	1.01	0.75	13.89	36.26	3.58	21.87	1.77	0.41	39.38	28.74
16-18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18-20	1.72	58.41	19.10	7.60	14.48	5.57	10.60	5.50	2.72	32.21	12.20	1.38	0.36	13.59	35.99	3.84	22.54	1.68	0.36	37.07	27.15
20-22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22-24	1.47	54.15	18.00	6.58	13.51	5.21	10.19	4.80	2.17	28.66	10.95	1.36	0.65	13.03	33.79	3.20	20.72	1.63	0.32	35.06	26.21
24-26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26-28	2.27	57.32	19.64	7.27	13.76	5.46	10.80	5.34	2.38	28.74	11.37	1.36	0.66	13.73	35.51	3.42	21.62	1.63	0.35	33.49	28.39
28-30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30-32	1.55	55.29	18.25	6.59	13.85	5.44	9.89	4.95	2.00	26.06	10.41	1.19	0.63	13.03	34.21	3.38	20.25	1.60	0.26	31.90	26.68
32-34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
34-36	1.79	59.26	20.15	7.68	14.38	5.24	10.72	5.38	2.39	24.64	10.08	1.61	0.64	13.82	36.73	3.59	22.12	1.69	0.46	30.22	26.86
36-38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
38-40	1.38	61.44	18.50	7.25	14.86	5.20	10.26	5.25	1.92	23.02	9.37	1.53	0.82	13.73	37.09	3.47	21.50	1.68	0.45	29.96	24.49
40-42	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
42-44	1.77	58.49	18.43	6.72	14.00	5.37	10.24	5.05	2.06	23.23	9.40	1.39	0.35	13.83	36.94	3.42	21.52	1.66	0.60	29.86	26.27
44-46	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
46-48	1.68	59.51	18.01	6.67	13.74	5.13	9.90	4.85	1.69	16.65	7.00	1.36	0.40	12.77	36.65	3.31	21.10	1.76	0.49	22.47	24.35
48-50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND not determined

B4.1. TRANSECT CORES: 23-25/3/92
Major element concentrations (salt-free)

Core No. / Depth Interval	Si (wt.%)	Al (wt.%)	Fe (wt.%)	Mg (wt.%)	Ca (wt.%)	Na (wt.%)	K (wt.%)	Ti (wt.%)	Mn (wt.%)	P (wt.%)	Org-C (wt.%)	N (wt.%)	C/N Ratio	Salt Content (wt.%)	Porosity (vol.%)	Fe/Mn Ratio
1/0-1	26.23	7.32	3.00	1.11	1.20	1.81	2.29	0.39	0.041	0.145	7.560	0.359	18.1	8.23	88.5	73.9
1/1-2	26.88	7.20	3.05	1.11	1.34	1.88	2.32	0.39	0.050	0.152	ND	ND	ND	6.92	86.6	61.1
1/2-3	27.21	7.14	3.03	1.12	1.21	1.98	2.29	0.37	0.044	0.141	6.071	0.237	22.0	6.52	85.9	69.0
1/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.12	85.1	ND
1/4-5	26.50	7.01	3.09	1.12	1.21	2.10	2.32	0.37	0.040	0.138	6.405	0.298	18.4	6.08	85.0	78.1
1/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.14	82.8	ND
1/6-7	27.52	7.17	3.08	1.13	1.22	2.14	2.41	0.39	0.037	0.122	5.738	0.212	23.2	4.27	80.0	82.7
2/0-1	23.33	7.15	3.42	1.23	1.68	1.97	2.16	1.60	0.044	0.155	7.722	0.377	17.5	8.90	89.3	77.3
2/1-2	25.50	7.31	3.67	1.27	1.17	1.83	2.24	0.40	0.040	0.149	7.547	0.322	20.1	8.22	88.5	92.4
2/2-3	25.39	8.01	3.82	1.29	1.15	1.89	2.26	0.40	0.043	0.142	ND	ND	ND	8.25	88.5	88.7
2/3-4	25.58	7.54	3.99	1.33	1.15	2.05	2.23	0.39	0.040	0.138	7.544	0.325	19.9	8.13	88.4	98.6
2/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.66	87.7	ND
2/5-6	25.31	7.47	3.79	1.33	1.18	1.81	2.23	0.41	0.040	0.136	7.540	0.349	18.5	7.25	87.1	94.6
2/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.99	86.7	ND
2/7-8	25.41	7.28	3.81	1.36	1.18	1.93	2.28	0.41	0.043	0.129	7.357	0.295	21.3	6.70	86.2	88.2
3/1-2	26.38	7.36	3.53	1.18	1.05	1.91	2.37	0.39	0.047	0.132	6.582	0.286	19.7	8.36	88.6	74.5
3/2-3	26.27	7.46	3.52	1.21	1.05	1.95	2.41	0.39	0.047	0.124	6.531	0.278	20.2	6.96	86.7	74.2
3/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.45	85.8	ND
3/4-5	26.35	7.50	3.48	1.24	1.09	2.02	2.52	0.40	0.052	0.121	6.212	0.256	20.8	6.06	85.0	66.9
3/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.80	84.4	ND
3/6-7	26.76	7.45	3.25	1.18	1.09	2.05	2.65	0.38	0.044	0.122	6.303	0.253	21.3	5.64	84.1	74.8
4/0-1	24.17	6.97	4.93	1.30	1.11	1.50	1.96	0.39	0.175	0.296	8.316	0.448	15.9	12.17	91.9	28.2
4/1-2	24.15	7.09	4.55	1.38	1.15	1.85	2.05	0.40	0.097	0.232	ND	ND	ND	9.69	90.0	47.0
4/2-3	24.20	7.00	4.54	1.38	1.18	1.77	2.08	0.40	0.090	0.210	8.374	0.412	17.4	8.39	88.7	50.6
4/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.57	87.6	ND
4/4-5	25.67	7.57	4.41	1.54	1.15	2.13	2.21	0.42	0.078	0.143	8.215	0.391	18.0	7.92	88.1	56.3
4/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.03	88.2	ND
4/6-7	24.61	7.22	4.20	1.42	1.12	1.86	2.18	0.42	0.073	0.150	8.150	0.394	17.7	7.80	87.9	57.4
4/7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.70	87.8	ND
4/8-9	24.66	7.26	4.10	1.42	1.22	1.91	2.20	0.42	0.059	0.131	7.847	0.347	19.4	7.45	87.4	69.1
5/0-1	24.27	7.22	4.79	1.55	1.10	2.08	1.93	0.40	0.417	0.207	8.031	0.397	17.4	12.52	92.1	11.5
5/1-2	24.21	7.23	4.83	1.45	1.22	2.09	2.08	0.41	0.198	0.186	7.868	0.390	17.3	9.99	90.3	24.4
5/2-3	24.43	7.13	4.49	1.40	1.11	1.87	2.11	0.41	0.164	0.165	ND	ND	ND	8.94	89.3	27.4
5/3-4	24.49	7.08	4.52	1.40	1.09	1.89	2.17	0.41	0.158	0.162	8.127	0.417	16.7	8.47	88.8	28.5
5/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.25	88.5	ND
5/5-6	24.60	7.36	4.52	1.50	1.08	2.09	2.16	0.42	0.140	0.145	7.861	0.392	17.2	8.19	88.4	32.3
5/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.34	88.6	ND
5/7-8	24.73	7.11	4.62	1.42	1.08	2.01	2.15	0.42	0.114	0.134	7.824	0.375	17.9	7.90	88.1	40.7
5/8-9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.96	88.1	ND
5/9-10	25.03	7.38	4.36	1.45	1.08	1.91	2.16	0.42	0.101	0.134	7.880	0.373	18.1	7.84	88.0	43.2

ND not determined

B4.1.(continued) TRANSECT CORES: 23-25/3/92

Major element concentrations (salt-free)

Core No. / Depth Interval	Si (wt.%)	Al (wt.%)	Fe (wt.%)	Mg (wt.%)	Ca (wt.%)	Na (wt.%)	K (wt.%)	Ti (wt.%)	Mn (wt.%)	P (wt.%)	Org-C (wt.%)	N (wt.%)	C/N Ratio	Salt Content (wt.%)	Porosity (vol.%)	
6/0-1	20.40	6.31	4.96	1.66	1.21	1.54	1.52	0.34	5.351	0.274	7.991	0.452	15.2	17.29	94.2	0.9
6/1-2	20.24	6.21	5.41	1.71	1.28	1.41	1.63	0.35	3.910	0.299	8.501	0.484	15.1	15.41	93.5	1.4
6/2-3	20.65	6.29	5.46	1.71	1.29	1.50	1.63	0.35	1.925	0.361	ND	ND	ND	14.97	93.3	2.8
6/3-4	21.39	7.46	5.13	1.81	1.24	1.82	1.84	0.36	1.142	0.252	9.720	0.571	14.6	14.04	92.9	4.5
6/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	13.00	92.4	ND
6/5-6	24.38	7.48	5.37	2.36	1.15	2.29	1.81	0.36	1.160	0.169	8.423	0.463	15.6	12.24	92.0	4.6
6/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	11.93	91.8	ND
6/7-8	21.96	7.32	5.07	1.90	1.29	1.86	1.93	0.37	1.494	0.154	8.129	0.431	16.2	11.21	91.3	3.4
6/8-9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.92	91.1	ND
6/9-10	24.28	7.50	5.75	2.23	1.10	2.17	1.92	0.39	0.823	0.143	7.544	0.391	16.5	10.89	91.0	7.0
6/10-11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	11.24	91.3	ND
6/11-12	23.05	7.14	5.88	1.85	1.07	1.56	2.02	0.41	0.429	0.128	7.399	0.372	17.0	10.73	90.9	13.7
6/12-13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.67	90.9	ND
6/13-14	23.34	7.48	5.39	1.95	1.00	2.00	2.02	0.39	0.412	0.123	7.376	0.384	16.4	10.11	90.4	13.1
D/0-1	22.71	7.37	5.68	1.80	1.17	1.49	1.76	0.42	1.060	0.234	4.012	0.375	9.2	14.23	93.0	5.4
D/1-2	22.95	7.71	5.74	1.81	1.16	1.39	1.98	0.43	0.532	0.225	ND	ND	ND	13.07	92.4	10.8
D/2-3	23.00	7.49	5.57	1.87	1.14	1.67	1.93	0.42	0.419	0.188	3.810	0.369	8.8	11.92	91.8	13.3
D/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	11.42	91.4	ND
D/4-5	23.34	7.40	5.53	1.82	1.19	1.46	1.87	0.44	0.568	0.155	3.017	0.287	9.0	11.50	91.5	9.7
D/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	11.74	91.6	ND
D/6-7	23.42	7.45	5.34	1.80	1.14	1.67	2.02	0.44	0.500	0.151	3.836	0.363	9.1	11.65	91.6	10.7
D/7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	11.37	91.4	ND
D/8-9	23.69	7.55	5.53	1.78	1.11	1.62	1.91	0.44	0.290	0.141	3.539	0.326	9.3	10.78	91.0	19.1
D/9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.73	90.9	ND
D/10-11	23.85	7.49	5.62	1.74	1.10	1.39	1.91	0.45	0.309	0.143	3.664	0.332	9.5	10.44	90.7	18.2
D/11-12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.78	90.1	ND
D/12-13	23.99	7.51	5.51	1.75	1.09	1.62	1.98	0.45	0.283	0.139	3.421	0.324	9.1	9.42	89.8	19.5
9/0-1	23.56	7.61	5.79	1.74	1.79	0.95	1.93	0.45	0.232	0.256	3.229	0.330	8.4	11.02	91.1	24.9
9/1-2	23.51	8.32	5.93	1.78	1.30	1.20	2.02	0.47	0.136	0.260	ND	ND	ND	9.46	89.8	43.6
9/2-3	23.53	7.93	5.94	1.82	1.44	1.23	2.07	0.47	0.120	0.257	2.974	0.329	7.8	8.05	88.3	49.3
9/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.77	87.9	ND
9/4-5	23.66	7.84	5.17	1.74	1.33	1.25	2.18	0.45	0.066	0.232	2.873	0.334	7.4	8.00	88.2	77.7
9/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.30	87.2	ND
9/6-7	23.73	7.70	5.37	1.71	1.25	1.29	2.16	0.45	0.054	0.160	3.026	0.356	7.3	7.05	86.8	99.2
9/7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.79	86.4	ND
9/8-9	24.00	7.66	5.36	1.79	1.15	1.32	2.17	0.46	0.049	0.142	2.619	0.304	7.4	6.88	86.5	109.1
10/0-1	23.66	13.08	4.76	1.47	3.09	0.99	2.03	0.41	0.156	0.202	2.394	0.301	6.8	10.43	90.7	30.6
10/1-2	24.54	10.30	4.93	1.56	1.97	1.27	2.11	0.43	0.083	0.204	2.454	0.309	6.8	8.19	88.4	59.6
10/2-3	24.84	8.62	4.81	1.57	1.61	1.23	2.09	0.43	0.067	0.190	ND	ND	ND	7.72	87.8	71.6
10/3-4	25.41	8.25	4.64	1.58	1.57	1.38	2.12	0.42	0.058	0.177	2.479	0.306	7.0	7.22	87.1	79.5
10/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.90	86.6	ND
10/5-6	25.75	7.83	4.52	1.56	1.44	1.44	2.17	0.43	0.050	0.145	2.366	0.268	7.6	6.29	85.4	91.1
10/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.96	84.8	ND
10/7-8	26.30	7.48	4.39	1.54	1.31	1.52	2.16	0.43	0.044	0.131	2.100	0.254	7.1	5.63	84.0	99.0
11/0-1	30.18	5.79	2.47	0.77	4.24	1.66	1.94	0.26	0.068	0.090	0.842	0.133	5.4	3.04	73.9	36.4
11/1-2	32.10	5.86	2.18	0.71	3.39	1.79	2.03	0.26	0.041	0.070	0.778	0.122	5.5	1.94	64.4	53.1
11/2-3	32.67	5.80	2.01	0.65	3.01	1.84	2.03	0.26	0.029	0.057	ND	ND	ND	1.66	60.8	68.8
11/3-4	32.70	5.68	1.83	0.60	3.39	1.95	2.04	0.25	0.027	0.051	0.544	0.137	3.4	1.26	54.1	66.8
11/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.19	52.6	ND
11/5-6	32.48	5.64	1.86	0.59	3.75	1.93	2.02	0.24	0.027	0.048	0.569	0.106	4.6	1.17	52.1	67.9
11/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.07	50.1	ND
11/7-8	33.22	5.81	2.02	0.65	3.14	1.90	2.06	0.24	0.031	0.050	0.577	0.103	4.8	1.12	51.2	64.6

ND not determined

B4.2. TRANSECT CORES: 23-25/3/92

Major elements (salt-free) ratioed to Al

Core No. / Depth Interval	Si/Al	Fe/Al	Mg/Al	Ca/Al	Na/Al	K/Al	Ti/Al	Mn/Al	P/Al	org-C/Al	N/Al
1/0-1	3.58	0.41	0.15	0.16	0.25	0.31	0.053	0.006	0.020	1.033	0.049
1/1-2	3.73	0.42	0.15	0.19	0.26	0.32	0.054	0.007	0.021	ND	ND
1/2-3	3.81	0.42	0.16	0.17	0.28	0.32	0.052	0.006	0.020	0.850	0.033
1/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1/4-5	3.78	0.44	0.16	0.17	0.30	0.33	0.053	0.006	0.020	0.914	0.042
1/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1/6-7	3.84	0.43	0.16	0.17	0.30	0.34	0.054	0.005	0.017	0.800	0.030
2/0-1	3.26	0.48	0.17	0.24	0.28	0.30	0.224	0.006	0.022	1.081	0.053
2/1-2	3.49	0.50	0.17	0.16	0.25	0.31	0.055	0.005	0.020	1.032	0.044
2/2-3	3.17	0.48	0.16	0.14	0.24	0.28	0.050	0.005	0.018	ND	ND
2/3-4	3.39	0.53	0.18	0.15	0.27	0.30	0.052	0.005	0.018	1.001	0.043
2/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2/5-6	3.39	0.51	0.18	0.16	0.24	0.30	0.055	0.005	0.018	1.009	0.047
2/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2/7-8	3.49	0.52	0.19	0.16	0.26	0.31	0.056	0.006	0.018	1.011	0.041
3/1-2	3.58	0.48	0.16	0.14	0.26	0.32	0.053	0.006	0.018	0.894	0.039
3/2-3	3.52	0.47	0.16	0.14	0.26	0.32	0.053	0.006	0.017	0.876	0.037
3/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3/4-5	3.51	0.46	0.17	0.14	0.27	0.34	0.053	0.007	0.016	0.828	0.034
3/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3/6-7	3.59	0.44	0.16	0.15	0.27	0.36	0.051	0.006	0.016	0.846	0.034
4/0-1	3.47	0.71	0.19	0.16	0.21	0.28	0.056	0.025	0.042	1.194	0.064
4/1-2	3.41	0.64	0.19	0.16	0.26	0.29	0.057	0.014	0.033	ND	ND
4/2-3	3.46	0.65	0.20	0.17	0.25	0.30	0.058	0.013	0.030	1.196	0.059
4/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4/4-5	3.39	0.58	0.20	0.15	0.28	0.29	0.056	0.010	0.019	1.085	0.052
4/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4/6-7	3.41	0.58	0.20	0.16	0.26	0.30	0.058	0.010	0.021	1.129	0.055
4/7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4/8-9	3.40	0.57	0.19	0.17	0.26	0.30	0.058	0.008	0.018	1.080	0.048
5/0-1	3.36	0.66	0.22	0.15	0.29	0.27	0.055	0.058	0.029	1.113	0.055
5/1-2	3.35	0.67	0.20	0.17	0.29	0.29	0.057	0.027	0.026	1.088	0.054
5/2-3	3.43	0.63	0.20	0.16	0.26	0.30	0.057	0.023	0.023	ND	ND
5/3-4	3.46	0.64	0.20	0.15	0.27	0.31	0.058	0.022	0.023	1.147	0.059
5/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5/5-6	3.34	0.61	0.20	0.15	0.28	0.29	0.057	0.019	0.020	1.068	0.053
5/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5/7-8	3.48	0.65	0.20	0.15	0.28	0.30	0.059	0.016	0.019	1.100	0.053
5/8-9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5/9-10	3.39	0.59	0.20	0.15	0.26	0.29	0.057	0.014	0.018	1.068	0.051

ND not determined

B4.2.(continued) TRANSECT CORES: 23-25/3/92

Core No. / Depth Interval	Major elements (salt-free) ratioed to Al										
	Si/Al	Fe/Al	Mg/Al	Ca/Al	Na/Al	K/Al	Ti/Al	Mn/Al	P/Al	org-C/Al	N/Al
6/0-1	3.23	0.79	0.26	0.19	0.24	0.24	0.054	0.848	0.043	1.266	0.072
6/1-2	3.26	0.87	0.28	0.21	0.23	0.26	0.056	0.629	0.048	1.368	0.078
6/2-3	3.29	0.87	0.27	0.21	0.24	0.26	0.056	0.306	0.057	ND	ND
6/3-4	2.87	0.69	0.24	0.17	0.24	0.25	0.049	0.153	0.034	1.304	0.077
6/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/5-6	3.26	0.72	0.32	0.15	0.31	0.24	0.048	0.155	0.023	1.126	0.062
6/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/7-8	3.00	0.69	0.26	0.18	0.25	0.26	0.051	0.204	0.021	1.111	0.059
6/8-9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/9-10	3.24	0.77	0.30	0.15	0.29	0.26	0.052	0.110	0.019	1.006	0.052
6/10-11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/11-12	3.23	0.82	0.26	0.15	0.22	0.28	0.057	0.060	0.018	1.037	0.052
6/12-13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/13-14	3.12	0.72	0.26	0.13	0.27	0.27	0.052	0.055	0.016	0.986	0.051
D/0-1	3.08	0.77	0.24	0.16	0.20	0.24	0.057	0.144	0.032	0.545	0.051
D/1-2	2.98	0.75	0.23	0.15	0.18	0.26	0.055	0.069	0.029	ND	ND
D/2-3	3.07	0.74	0.25	0.15	0.22	0.26	0.056	0.056	0.025	0.509	0.049
D/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D/4-5	3.15	0.75	0.25	0.16	0.20	0.25	0.059	0.077	0.021	0.408	0.039
D/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D/6-7	3.14	0.72	0.24	0.15	0.22	0.27	0.058	0.067	0.020	0.515	0.049
D/7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D/8-9	3.14	0.73	0.24	0.15	0.21	0.25	0.058	0.038	0.019	0.469	0.043
D/9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D/10-11	3.18	0.75	0.23	0.15	0.19	0.26	0.060	0.041	0.019	0.489	0.044
D/11-12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D/12-13	3.19	0.73	0.23	0.15	0.22	0.26	0.060	0.038	0.018	0.455	0.043
9/0-1	3.10	0.76	0.23	0.23	0.13	0.25	0.059	0.031	0.034	0.424	0.043
9/1-2	2.83	0.71	0.21	0.16	0.14	0.24	0.056	0.016	0.031	ND	ND
9/2-3	2.97	0.75	0.23	0.18	0.15	0.26	0.059	0.015	0.032	0.375	0.041
9/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9/4-5	3.02	0.66	0.22	0.17	0.16	0.28	0.057	0.008	0.030	0.367	0.043
9/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9/6-7	3.08	0.70	0.22	0.16	0.17	0.28	0.059	0.007	0.021	0.393	0.046
9/7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9/8-9	3.13	0.70	0.23	0.15	0.17	0.28	0.060	0.006	0.019	0.342	0.040
10/0-1	1.81	0.36	0.11	0.24	0.08	0.16	0.031	0.012	0.015	0.183	0.023
10/1-2	2.38	0.48	0.15	0.19	0.12	0.20	0.041	0.008	0.020	0.238	0.030
10/2-3	2.88	0.56	0.18	0.19	0.14	0.24	0.050	0.008	0.022	ND	ND
10/3-4	3.08	0.56	0.19	0.19	0.17	0.26	0.051	0.007	0.021	0.301	0.037
10/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10/5-6	3.29	0.58	0.20	0.18	0.18	0.28	0.055	0.006	0.019	0.302	0.034
10/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10/7-8	3.52	0.59	0.21	0.18	0.20	0.29	0.057	0.006	0.018	0.281	0.034
11/0-1	5.21	0.43	0.13	0.73	0.29	0.34	0.046	0.012	0.016	0.145	0.023
11/1-2	5.48	0.37	0.12	0.58	0.31	0.35	0.044	0.007	0.012	0.133	0.021
11/2-3	5.64	0.35	0.11	0.52	0.32	0.35	0.045	0.005	0.010	ND	ND
11/3-4	5.76	0.32	0.11	0.60	0.34	0.36	0.043	0.005	0.009	0.096	0.024
11/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11/5-6	5.76	0.33	0.10	0.66	0.34	0.36	0.043	0.005	0.009	0.101	0.019
11/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11/7-8	5.71	0.35	0.11	0.54	0.33	0.35	0.042	0.005	0.009	0.099	0.018

ND not determined

B4.3. TRANSECT CORES: 23-25/3/92
Trace element concentrations (salt-free)

Core No / Depth Interval	Sc (ppm)	Ba (ppm)	V (ppm)	La (ppm)	Ce (ppm)	Nd (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Th (ppm)	U (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Mo (ppm)	I (ppm)	Br (ppm)
1/0-1	11.9	709	79	31.3	64.5	26.9	92.1	34.0	8.5	85.9	46.0	8.1	9.2	90.4	397	16.5	225	12.7	3.3	74	69
1/1-2	10.0	719	79	33.0	64.6	29.3	56.8	24.0	7.2	85.2	46.4	9.1	10.5	91.3	407	16.2	227	13.0	3.9	101	76
1/2-3	8.7	715	85	41.1	71.0	28.7	54.3	22.6	7.7	84.4	48.2	6.8	8.3	88.9	400	16.0	222	12.8	5.1	99	77
1/3-4	11.2	694	88	32.4	70.0	30.0	50.4	23.0	6.9	85.4	50.4	6.6	9.8	86.8	392	15.8	224	12.5	4.8	85	72
1/4-5	8.8	693	90	36.4	68.5	28.3	52.0	23.7	8.7	89.8	52.0	7.3	10.5	87.6	400	17.0	219	13.0	4.2	113	83
1/5-6	7.4	701	87	35.6	73.9	32.0	51.2	22.7	8.6	85.4	47.4	7.7	10.0	89.3	398	15.6	225	12.5	5.4	117	73
1/6-7	8.1	742	83	38.1	74.1	31.2	55.7	25.9	11.6	88.8	47.8	7.4	9.6	90.3	404	17.2	227	13.2	6.4	90	64
2/0-1	10.4	622	102	48.5	91.9	35.6	60.9	28.9	11.9	140.9	70.5	11.4	8.6	97.3	367	19.6	183	14.1	2.9	205	100
2/1-2	10.4	608	109	48.2	85.4	32.8	60.6	30.9	10.8	129.8	69.6	9.5	8.9	95.2	367	21.1	180	13.7	3.1	202	100
2/2-3	9.7	614	107	41.9	80.8	35.9	62.1	29.0	11.4	134.9	68.5	9.7	8.5	95.5	363	19.9	178	14.0	3.6	199	97
2/3-4	10.2	634	106	40.7	89.9	37.3	59.4	28.2	12.8	135.3	68.4	10.8	10.0	95.1	362	20.6	178	13.4	4.2	185	93
2/4-5	9.2	627	105	42.0	95.3	38.3	65.4	31.7	13.2	135.7	69.7	10.4	8.7	95.5	365	20.7	179	14.2	4.4	170	89
2/5-6	11.9	642	109	41.5	93.9	34.0	61.6	31.6	13.6	137.3	68.0	9.6	9.4	95.1	363	20.9	180	14.2	4.1	154	87
2/6-7	9.9	620	110	44.6	89.9	35.4	61.9	28.6	15.1	138.6	69.2	10.2	8.7	94.8	363	20.8	181	13.9	4.3	144	91
2/7-8	10.2	627	107	41.7	84.6	34.4	63.5	29.8	15.8	143.8	70.5	9.2	8.1	96.0	361	20.7	178	13.5	4.1	154	90
3/1-2	8.4	595	110	47.2	83.7	33.4	59.4	28.5	14.3	142.1	68.5	11.8	10.0	105.4	331	20.7	176	14.2	3.6	168	95
3/2-3	11.2	589	107	46.3	91.5	33.1	64.1	29.6	15.0	139.6	67.3	11.1	11.1	107.7	328	21.8	180	14.4	3.9	173	99
3/3-4	9.6	588	109	50.6	91.2	36.3	62.3	30.4	13.9	136.6	67.4	12.9	11.5	106.6	329	21.6	178	13.8	3.8	172	104
3/4-5	10.0	611	111	50.5	104.0	38.3	62.3	32.0	13.7	128.3	62.4	13.5	13.2	106.7	332	21.6	184	14.9	3.5	152	93
3/5-6	7.2	607	106	48.9	87.2	32.6	61.4	30.4	13.9	125.5	64.1	12.6	11.4	109.4	329	20.9	180	15.5	3.7	152	99
3/6-7	11.8	611	107	46.1	101.8	36.2	59.8	29.4	16.5	119.3	62.7	13.1	10.2	112.6	325	19.9	179	14.8	2.6	133	88
4/0-1	10.5	524	112	47.4	94.2	35.6	56.0	29.1	9.0	159.2	78.2	9.0	8.4	98.3	360	22.1	167	14.0	3.3	511	147
4/1-2	10.3	545	117	50.1	97.1	41.4	61.9	29.3	11.2	164.2	81.5	9.4	7.9	95.9	354	23.9	166	13.5	2.4	413	149
4/2-3	10.0	546	122	48.1	93.8	35.6	61.3	31.2	12.8	167.0	81.4	10.3	6.9	97.3	340	22.5	165	14.0	2.3	379	155
4/3-4	12.0	555	121	54.3	104.7	37.6	63.6	30.2	13.1	165.7	79.7	10.0	8.1	96.0	333	23.5	167	14.1	2.6	358	149
4/4-5	9.7	566	122	54.7	101.1	40.1	64.0	31.9	12.4	169.0	79.1	10.5	9.6	98.0	327	23.6	169	13.1	2.5	300	136
4/5-6	13.6	547	124	49.0	98.2	38.7	64.6	30.8	12.9	171.3	82.1	11.6	9.8	97.3	323	23.2	166	13.8	3.6	282	128
4/6-7	9.1	551	128	52.4	95.9	35.4	62.6	30.8	15.2	170.8	78.3	10.7	7.7	96.9	325	22.9	167	14.1	3.6	283	127
4/7-8	12.6	563	119	42.6	101.5	38.5	63.4	32.1	14.3	162.0	74.4	11.4	10.7	98.7	326	22.1	173	14.6	3.3	259	120
4/8-9	9.5	571	122	52.9	103.9	43.7	62.0	32.8	13.5	151.8	71.7	12.5	9.0	99.2	335	23.3	177	14.8	3.3	239	117
5/0-1	7.5	471	120	46.3	95.0	39.1	56.8	30.7	8.8	186.1	80.5	9.7	6.6	95.7	333	24.1	186	13.7	4.8	488	147
5/1-2	12.7	494	134	49.8	97.2	36.2	62.9	31.8	11.1	194.3	82.7	9.2	8.9	94.3	321	25.1	192	13.2	2.4	410	156
5/2-3	11.0	514	137	53.0	99.3	42.9	64.6	33.2	13.7	193.1	82.1	9.9	7.0	95.7	313	24.3	178	13.1	2.2	356	148
5/3-4	7.9	501	134	54.7	105.4	42.1	64.1	32.9	15.1	193.9	81.4	10.2	8.7	95.4	310	24.6	180	14.5	2.0	356	142
5/4-5	12.2	526	141	51.8	94.9	39.6	63.3	34.8	15.8	193.2	82.5	10.6	8.1	94.8	306	24.6	180	13.5	2.6	334	148
5/5-6	13.2	509	142	50.9	106.7	40.5	69.2	34.7	15.0	194.3	84.7	11.7	8.1	95.3	307	25.4	182	13.5	3.7	320	137
5/6-7	12.5	533	135	53.1	110.3	42.0	69.8	33.9	13.9	189.5	81.7	9.6	7.9	96.3	308	25.3	191	13.4	4.4	310	129
5/7-8	11.0	524	138	51.4	96.1	37.3	65.7	35.4	13.0	180.0	76.3	10.0	10.0	95.9	311	24.8	192	13.7	3.6	293	129
5/8-9	6.5	566	141	56.1	107.0	38.4	68.9	34.8	14.6	180.5	78.5	12.1	9.3	97.9	313	24.3	195	13.9	3.5	286	129
5/9-10	9.4	541	141	53.2	109.8	40.0	70.3	34.5	14.2	175.5	78.2	9.7	9.5	96.9	314	25.1	197	13.9	4.6	276	120

B4.3. TRANSECT CORES: 23-25/3/92

Trace element concentrations (continued)

Core No / Depth Interval	Sc (ppm)	Ba (ppm)	V (ppm)	La (ppm)	Ce (ppm)	Nd (ppm)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Th (ppm)	U (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Mo (ppm)	I (ppm)	Br (ppm)
6/0-1	8.5	431	136	42.0	75.7	22.5	45.0	30.1	1.7	228.4	82.8	5.0	9.7	90.7	438	21.8	129	11.4	23.9	1040	196
6/1-2	5.8	498	145	43.4	76.6	31.0	52.1	31.7	4.0	240.8	93.3	5.4	5.8	88.7	441	22.8	118	11.8	9.6	942	218
6/2-3	10.7	439	157	50.9	90.9	35.2	54.2	33.4	7.1	248.3	96.0	6.6	5.1	91.0	382	23.2	122	11.6	4.2	869	222
6/3-4	7.6	398	177	48.2	91.3	33.4	57.9	34.4	8.8	257.2	100.6	8.5	7.1	91.1	314	24.4	123	11.6	2.4	687	213
6/4-5	11.0	393	160	52.9	99.1	37.9	60.5	34.5	10.1	261.5	101.0	6.2	7.6	91.6	295	23.9	126	10.6	2.2	536	190
6/5-6	12.2	395	160	54.5	90.4	35.4	61.2	37.0	13.1	262.0	103.8	8.4	7.4	92.5	284	24.8	128	12.8	3.6	500	174
6/6-7	10.4	403	156	50.3	91.6	36.4	63.0	35.2	12.0	256.2	98.8	6.6	5.1	91.7	285	24.8	129	11.8	4.1	461	168
6/7-8	9.9	412	159	47.1	93.7	36.8	62.1	36.6	12.2	247.2	96.1	6.5	7.9	89.4	286	24.4	132	12.6	5.0	423	156
6/8-9	8.3	410	163	50.9	99.2	36.9	65.8	36.6	14.9	256.4	98.2	6.8	7.0	90.5	281	25.4	134	12.0	5.4	450	155
6/9-10	9.1	420	156	52.0	95.8	37.6	65.1	39.3	13.6	256.6	100.8	8.1	5.7	93.4	279	26.5	141	12.1	6.4	453	152
6/10-11	9.0	416	149	53.5	101.4	38.0	67.4	38.1	14.6	257.7	99.3	8.8	7.2	96.9	279	26.1	144	12.3	6.9	449	142
6/11-12	10.1	432	158	54.3	96.3	36.7	65.4	39.0	16.7	252.1	98.5	6.7	7.6	98.0	284	24.1	138	12.3	5.7	423	136
6/12-13	11.8	434	155	51.0	105.8	38.4	69.1	38.2	14.2	241.0	99.2	8.7	7.9	98.5	285	25.5	142	12.5	5.6	398	137
6/13-14	9.7	458	150	57.1	105.0	42.0	69.1	36.8	13.0	226.3	95.8	10.0	9.0	98.6	283	24.8	138	12.3	5.0	360	140
D/0-1	13.2	420	140	53.5	101.0	36.4	71.0	37.0	12.5	238.3	89.3	6.2	5.9	102.7	315	26.5	159	12.6	4.8	512	223
D/1-2	14.1	426	144	49.0	94.8	38.3	78.2	39.7	16.7	245.7	91.8	4.9	5.6	103.0	289	26.0	159	12.5	2.9	454	219
D/2-3	11.5	429	153	51.2	106.7	46.7	78.8	39.7	17.8	252.2	97.2	7.2	6.9	103.2	276	27.1	160	14.0	2.0	405	231
D/3-4	13.3	439	150	52.0	100.6	42.1	75.9	40.1	20.0	243.8	93.5	6.9	6.3	101.4	276	26.5	162	12.8	1.5	359	219
D/4-5	10.5	427	149	49.3	92.7	40.0	79.4	40.5	16.6	244.1	96.3	8.1	7.1	103.6	270	27.1	162	12.9	2.1	336	211
D/5-6	12.5	424	143	48.4	92.7	38.4	78.1	39.5	14.8	239.9	92.7	6.9	6.3	103.1	267	25.8	164	12.8	1.9	325	203
D/6-7	7.9	426	144	49.8	101.4	42.8	80.9	41.9	16.2	238.9	92.7	7.0	6.8	102.4	265	25.9	159	12.9	1.9	321	205
D/7-8	11.5	429	152	56.9	97.5	42.5	79.1	40.4	16.5	238.4	93.0	6.5	6.0	102.2	265	26.0	162	12.2	2.8	290	200
D/8-9	10.2	432	145	50.5	105.1	41.4	78.3	41.8	18.0	235.3	91.6	8.4	5.9	103.2	268	26.8	170	12.9	2.1	282	197
D/9-10	13.9	441	143	53.1	99.6	39.3	80.0	39.3	15.6	236.8	90.7	6.6	5.7	102.4	269	26.7	167	12.9	2.2	284	193
D/10-11	15.5	450	151	56.9	110.0	41.6	84.7	39.7	18.2	237.5	91.8	7.8	7.4	101.5	264	26.6	166	13.1	2.3	293	187
D/11-12	14.2	445	142	50.8	101.9	41.1	80.8	42.5	19.6	230.3	88.1	8.1	7.5	103.2	264	26.7	169	12.9	3.0	294	191
D/12-13	14.4	488	147	47.1	106.4	48.9	86.6	41.4	20.5	230.3	88.3	6.8	8.8	102.5	271	26.6	167	13.0	2.8	291	190
9/0-1	12.0	439	132	53.3	101.0	37.1	86.5	41.9	21.2	227.7	94.4	7.3	5.3	110.6	287	25.5	186	14.3	1.9	566	310
9/1-2	14.6	442	139	48.3	102.9	44.2	93.1	45.4	27.4	230.8	97.2	4.1	7.3	112.1	263	26.7	184	13.7	1.8	525	337
9/2-3	14.5	448	140	48.0	110.7	46.8	94.2	45.9	26.9	224.1	95.6	6.9	5.1	111.4	263	28.1	191	13.8	2.2	471	323
9/3-4	12.8	463	145	51.2	98.7	43.3	98.6	43.6	26.1	235.3	96.9	6.5	6.0	111.9	258	27.3	186	14.1	1.8	462	348
9/4-5	16.0	443	147	51.5	99.0	40.2	99.0	44.9	20.2	242.5	104.6	5.8	5.3	112.2	252	26.2	169	13.9	1.6	458	364
9/5-6	15.5	448	151	60.4	93.7	38.8	98.8	45.5	23.5	244.5	107.1	6.5	7.8	112.9	236	25.8	171	13.1	1.5	421	360
9/6-7	15.7	440	146	53.7	96.4	39.5	100.4	43.8	22.7	246.3	107.7	5.3	4.8	110.6	229	25.9	168	13.2	1.1	400	352
9/7-8	13.8	434	152	50.1	102.9	44.1	111.0	50.2	24.8	248.9	107.2	7.3	5.1	113.4	228	25.3	170	14.2	1.8	373	337
9/8-9	14.3	455	149	54.7	105.6	41.3	100.3	45.6	24.3	249.6	104.7	5.6	7.8	113.4	228	26.1	168	13.5	1.5	344	320
10/0-1	12.7	429	121	44.9	92.2	41.1	79.0	37.5	18.1	202.6	84.1	4.7	5.6	106.2	327	22.8	210	13.3	1.6	456	366
10/1-2	12.5	442	132	44.5	94.3	36.8	85.3	40.0	19.8	208.0	87.8	5.8	5.2	108.8	276	24.7	207	13.7	1.4	403	382
10/2-3	11.5	448	135	46.7	94.3	41.9	92.3	41.6	21.5	213.0	89.0	4.9	4.9	108.3	259	24.3	207	13.3	1.3	390	400
10/3-4	12.5	458	131	50.2	89.9	37.7	88.8	38.9	17.1	212.7	89.8	4.6	4.2	107.8	256	23.6	209	12.7	1.4	368	389
10/4-5	14.8	460	134	44.1	93.5	39.0	87.9	40.5	18.7	213.6	90.0	4.6	5.9	106.7	256	23.8	216	12.2	1.3	355	383
10/5-6	15.7	459	131	48.2	94.8	38.9	97.2	44.5	17.7	215.7	93.7	5.9	6.2	107.9	247	24.1	215	12.5	1.4	346	381
10/6-7	12.0	463	126	47.7	87.4	39.3	89.9	39.5	20.7	210.6	92.2	5.6	4.4	106.2	241	23.2	222	13.2	1.5	325	356
10/7-8	9.5	456	134	50.5	74.7	32.0	86.8	42.5	18.5	213.3	91.1	5.8	7.1	106.2	241	23.2	225	12.5	1.8	315	339
11/0-1	5.7	522	65	32.9	55.8	25.0	44.2	19.4	8.4	94.6	34.3	3.6	5.5	81.7	417	13.5	184	10.0	1.0	170	167
11/1-2	3.8	539	61	25.5	54.8	23.8	43.5	17.4	4.6	83.1	30.9	3.0	4.6	78.5	390	13.5	187	9.4	0.9	100	111
11/2-3	6.8	551	55	24.9	44.3	20.7	39.8	14.1	4.3	82.4	29.4	3.5	4.7	77.8	386	13.4	203	9.7	0.8	76	88
11/3-4	4.7	560	49	19.3	45.0	24.6	37.2	14.0	3.5	72.1	25.9	3.5	3.3	75.0	402	12.6	192	9.6	1.1	51	57
11/4-5	1.9	564	47	27.4	40.7	22.6	35.7	13.4	4.5	68.8	25.1	3.1	5.3	74.3	406	13.2	193	9.4	0.6	50	50
11/5-6	3.2	558	50	28.4	48.6	23.6	63.8	22.9	4.0	70.8	25.2	3.7	4.2	74.6	413	11.3	187	10.0	1.3	43	49
11/6-7	6.8	575	51	27.9	46.3	29.7	36.0	15.0	5.5	71.6	24.7	3.6	3.9	75.6	393	12.3	194	9.3	0.6	41	51
11/7-8	5.2	569	56	20.1	48.2	26.4	38.9	16.8	2.7	74.4	26.5	2.3	4.1	76.9	390	13.2	202	9.8	1.1	48	56

B4.4. TRANSECT CORES: 23-25/3/92
Trace elements (salt-free) ratioed to Al

Core No / Depth Interval	Sc/Al (x10-4)	Ba/Al (x10-4)	V/Al (x10-4)	La/Al (x10-4)	Ce/Al (x10-4)	Nd/Al (x10-4)	Cr/Al (x10-4)	Ni/Al (x10-4)	Cu/Al (x10-4)	Zn/Al (x10-4)	Pb/Al (x10-4)	Th/Al (x10-4)	U/Al (x10-4)	Rb/Al (x10-4)	Sr/Al (x10-4)	Y/Al (x10-4)	Zr/Al (x10-4)	Nb/al (x10-4)	Mo/Al (x10-4)	I/Al (x10-4)	Br/Al (x10-4)
1/0-1	1.62	97	10.78	4.27	8.81	3.68	12.58	4.65	1.16	11.7	6.28	1.10	1.25	12.36	54.2	2.25	30.7	1.74	0.45	10.1	9.4
1/1-2	1.39	100	11.03	4.58	8.97	4.07	7.89	3.33	1.00	11.8	6.45	1.27	1.46	12.69	56.5	2.25	31.6	1.81	0.54	14.0	10.6
1/2-3	1.21	100	11.91	5.75	9.95	4.02	7.61	3.16	1.08	11.8	6.76	0.96	1.17	12.45	56.1	2.25	31.0	1.80	0.72	13.8	10.8
1/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1/4-5	1.26	99	12.88	5.19	9.77	4.04	7.41	3.39	1.25	12.8	7.41	1.05	1.50	12.50	57.0	2.43	31.3	1.85	0.59	16.1	11.9
1/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1/6-7	1.14	103	11.55	5.32	10.33	4.36	7.76	3.61	1.62	12.4	6.67	1.03	1.34	12.59	56.3	2.40	31.7	1.84	0.89	12.5	9.0
2/0-1	1.46	87	14.26	6.79	12.86	4.98	8.53	4.04	1.66	19.7	9.86	1.60	1.20	13.61	51.4	2.75	25.6	1.97	0.40	28.6	14.0
2/1-2	1.42	83	14.96	6.59	11.68	4.49	8.28	4.23	1.48	17.7	9.52	1.30	1.22	13.02	50.2	2.89	24.6	1.88	0.42	27.7	13.6
2/2-3	1.21	77	13.30	5.22	10.08	4.48	7.75	3.62	1.43	16.8	8.54	1.21	1.06	11.92	45.3	2.49	22.3	1.74	0.45	24.8	12.1
2/3-4	1.36	84	14.04	5.40	11.93	4.95	7.89	3.74	1.70	18.0	9.07	1.43	1.33	12.63	48.0	2.73	23.7	1.78	0.56	24.6	12.3
2/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2/5-6	1.59	86	14.64	5.56	12.57	4.55	8.24	4.23	1.82	18.4	9.11	1.28	1.26	12.73	48.6	2.80	24.1	1.91	0.55	20.6	11.7
2/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2/7-8	1.40	86	14.76	5.73	11.62	4.73	8.72	4.09	2.16	19.8	9.69	1.27	1.12	13.20	49.6	2.84	24.5	1.86	0.56	21.1	12.4
3/1-2	1.14	81	14.94	6.42	11.37	4.53	8.06	3.87	1.94	19.3	9.31	1.60	1.36	14.32	44.9	2.82	23.9	1.93	0.49	22.9	12.8
3/2-3	1.50	79	14.38	6.21	12.26	4.44	8.59	3.96	2.02	18.7	9.02	1.48	1.48	14.44	44.0	2.93	24.2	1.93	0.52	23.2	13.3
3/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3/4-5	1.33	82	14.85	6.73	13.87	5.11	8.30	4.27	1.83	17.1	8.32	1.80	1.76	14.22	44.3	2.88	24.6	1.99	0.47	20.3	12.3
3/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3/6-7	1.58	82	14.40	6.19	13.67	4.87	8.02	3.94	2.22	16.0	8.42	1.76	1.37	15.11	43.6	2.67	24.0	1.99	0.36	17.9	11.8
4/0-1	1.50	75	16.10	6.80	13.52	5.12	8.04	4.18	1.29	22.8	11.23	1.29	1.21	14.11	51.6	3.17	23.9	2.01	0.47	73.4	21.2
4/1-2	1.45	77	16.52	7.06	13.71	5.84	8.74	4.14	1.58	23.2	11.50	1.33	1.11	13.53	50.0	3.38	23.4	1.91	0.34	58.2	21.0
4/2-3	1.43	78	17.40	6.87	13.39	5.08	8.76	4.46	1.82	23.9	11.63	1.47	0.98	13.89	48.6	3.21	23.6	2.00	0.33	54.1	22.2
4/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4/4-5	1.28	75	16.15	7.23	13.36	5.29	8.45	4.22	1.64	22.3	10.44	1.39	1.26	12.94	43.3	3.11	22.4	1.74	0.33	39.7	17.9
4/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4/6-7	1.26	76	17.74	7.26	13.29	4.90	8.67	4.27	2.10	23.7	10.85	1.49	1.07	13.42	45.0	3.17	23.1	1.95	0.50	39.2	17.6
4/7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4/8-9	1.31	79	16.83	7.29	14.31	6.01	8.54	4.52	1.86	20.9	9.88	1.73	1.23	13.66	46.2	3.21	24.3	2.04	0.46	32.9	16.1
5/0-1	1.05	65	16.69	6.41	13.16	5.42	7.87	4.26	1.22	25.8	11.15	1.35	0.92	13.26	46.1	3.34	25.8	1.90	0.67	67.6	20.4
5/1-2	1.75	68	18.49	6.88	13.44	5.01	8.69	4.39	1.54	26.9	11.43	1.27	1.23	13.04	44.4	3.47	26.6	1.83	0.34	56.7	21.5
5/2-3	1.54	72	19.17	7.44	13.93	6.03	9.06	4.65	1.93	27.1	11.53	1.39	0.99	13.42	43.9	3.41	25.0	1.83	0.31	49.9	20.7
5/3-4	1.11	71	18.97	7.73	14.88	5.94	9.05	4.64	2.13	27.4	11.49	1.43	1.23	13.47	43.7	3.47	25.3	2.05	0.28	50.2	20.1
5/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5/5-6	1.79	69	19.31	6.91	14.50	5.50	9.40	4.72	2.04	26.4	11.51	1.58	1.09	12.95	41.7	3.45	24.7	1.83	0.50	43.5	18.6
5/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5/7-8	1.54	74	19.46	7.22	13.51	5.25	9.23	4.98	1.83	25.3	10.73	1.40	1.40	13.48	43.7	3.48	27.0	1.92	0.50	41.2	18.1
5/8-9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5/9-10	1.28	73	19.07	7.20	14.88	5.43	9.53	4.68	1.93	23.8	10.60	1.31	1.29	13.13	42.6	3.40	26.6	1.88	0.62	37.4	16.3

ND not determined

B4.4. TRANSECT CORES: 23-25/3/92

Trace elements (salt-free) ratioed to Al (continued)

Core No / Depth Interval	Sc/Al (x10-4)	Ba/Al (x10-4)	V/Al (x10-4)	La/Al (x10-4)	Ce/Al (x10-4)	Nd/Al (x10-4)	Cr/Al (x10-4)	Ni/Al (x10-4)	Cu/Al (x10-4)	Zn/Al (x10-4)	Pb/Al (x10-4)	Th/Al (x10-4)	U/Al (x10-4)	Rb/Al (x10-4)	Sr/Al (x10-4)	Y/Al (x10-4)	Zr/Al (x10-4)	Nb/al (x10-4)	Mo/Al (x10-4)	I/Al (x10-4)	Br/Al (x10-4)
6/0-1	1.34	68	21.50	6.65	12.00	3.56	7.13	4.77	0.27	36.2	13.13	0.79	1.53	14.37	69.4	3.45	20.4	1.80	3.79	164.8	31.1
6/1-2	0.93	80	23.40	6.98	12.33	4.99	8.39	5.10	0.65	38.8	15.01	0.88	0.93	14.27	70.9	3.67	19.0	1.90	1.54	151.6	35.1
6/2-3	1.70	70	25.03	8.10	14.46	5.59	8.62	5.31	1.12	39.5	15.27	1.05	0.80	14.48	60.7	3.69	19.5	1.85	0.67	138.3	35.4
6/3-4	1.01	53	23.68	6.46	12.25	4.48	7.77	4.62	1.19	34.5	13.50	1.14	0.95	12.22	42.1	3.28	16.5	1.56	0.33	92.2	28.6
6/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/5-6	1.63	53	21.36	7.28	12.08	4.74	8.18	4.95	1.75	35.0	13.88	1.13	0.99	12.37	38.0	3.32	17.1	1.71	0.49	66.9	23.3
6/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/7-8	1.35	56	21.69	6.43	12.80	5.03	8.48	5.00	1.66	33.8	13.12	0.89	1.08	12.22	39.0	3.34	18.0	1.72	0.68	57.8	21.3
6/8-9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/9-10	1.21	56	20.85	6.93	12.78	5.01	8.68	5.24	1.81	34.2	13.43	1.08	0.76	12.45	37.1	3.53	18.8	1.62	0.85	60.4	20.3
6/10-11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/11-12	1.41	61	22.10	7.61	13.50	5.15	9.16	5.46	2.34	35.3	13.79	0.94	1.07	13.73	39.7	3.37	19.3	1.73	0.80	59.2	19.0
6/12-13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6/13-14	1.29	61	20.07	7.63	14.03	5.62	9.23	4.92	1.74	30.2	12.80	1.34	1.20	13.17	37.9	3.32	18.5	1.65	0.67	48.1	18.7
D/0-1	1.79	57	18.97	7.26	13.70	4.94	9.64	5.02	1.69	32.3	12.12	0.84	0.81	13.94	42.8	3.59	21.6	1.71	0.65	69.5	30.2
D/1-2	1.84	55	18.66	6.36	12.30	4.97	10.15	5.15	2.16	31.9	11.91	0.64	0.73	13.36	37.4	3.37	20.6	1.63	0.37	58.9	28.4
D/2-3	1.53	57	20.44	6.83	14.24	6.23	10.52	5.30	2.38	33.7	12.97	0.95	0.92	13.77	36.8	3.62	21.3	1.86	0.27	54.0	30.8
D/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D/4-5	1.42	58	20.09	6.66	12.52	5.41	10.74	5.47	2.25	33.0	13.01	1.10	0.96	14.01	36.5	3.67	21.9	1.74	0.29	45.4	28.5
D/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D/6-7	1.06	57	19.32	6.69	13.62	5.75	10.87	5.62	2.17	32.1	12.45	0.94	0.91	13.76	35.6	3.48	21.4	1.73	0.26	43.2	27.5
D/7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D/8-9	1.35	57	19.18	6.70	13.93	5.48	10.38	5.54	2.39	31.2	12.14	1.11	0.79	13.68	35.5	3.55	22.5	1.71	0.28	37.3	26.1
D/9-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D/10-11	2.07	60	20.15	7.60	14.68	5.56	11.31	5.30	2.43	31.7	12.25	1.04	0.98	13.54	35.2	3.55	22.2	1.74	0.31	39.1	25.0
D/11-12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
D/12-13	1.91	65	19.51	6.27	14.16	6.51	11.52	5.51	2.73	30.6	11.75	0.91	1.18	13.63	36.0	3.54	22.3	1.73	0.37	38.7	25.2
9/0-1	1.58	58	17.36	7.00	13.28	4.87	11.37	5.51	2.79	29.9	12.41	0.96	0.69	14.54	37.7	3.35	24.4	1.88	0.25	74.4	40.8
9/1-2	1.75	53	16.68	5.80	12.37	5.31	11.19	5.46	3.29	27.8	11.68	0.49	0.88	13.48	31.6	3.21	22.1	1.65	0.21	63.1	40.5
9/2-3	1.82	57	17.65	6.05	13.96	5.90	11.87	5.79	3.39	28.3	12.05	0.86	0.64	14.04	33.2	3.54	24.1	1.74	0.27	59.4	40.7
9/3-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9/4-5	2.04	57	18.77	6.58	12.64	5.13	12.64	5.73	2.58	30.9	13.35	0.74	0.68	14.32	32.1	3.34	21.5	1.78	0.21	58.4	46.5
9/5-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9/6-7	2.04	57	18.91	6.97	12.51	5.13	13.03	5.68	2.95	32.0	13.98	0.68	0.63	14.36	29.8	3.37	21.8	1.72	0.14	51.9	45.6
9/7-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9/8-9	1.87	59	19.50	7.14	13.79	5.40	13.10	5.96	3.17	32.6	13.68	0.73	1.02	14.81	29.8	3.41	21.9	1.77	0.20	45.0	41.7
10/0-1	0.97	33	9.27	3.43	7.05	3.14	6.04	2.87	1.38	15.5	6.43	0.36	0.43	8.12	25.0	1.74	16.0	1.02	0.12	34.9	28.0
10/1-2	1.22	43	12.80	4.33	9.16	3.58	8.28	3.88	1.93	20.2	8.53	0.56	0.51	10.57	26.8	2.40	20.1	1.33	0.14	39.1	37.1
10/2-3	1.33	52	15.70	5.42	10.94	4.86	10.71	4.83	2.49	24.7	10.32	0.57	0.57	12.56	30.1	2.82	24.0	1.55	0.15	45.2	46.4
10/3-4	1.52	56	15.92	6.09	10.90	4.57	10.77	4.72	2.08	25.8	10.88	0.56	0.51	13.07	31.0	2.86	25.3	1.54	0.17	44.6	47.2
10/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10/5-6	2.00	59	16.69	6.16	12.11	4.98	12.42	5.68	2.26	27.6	11.97	0.75	0.79	13.78	31.6	3.08	27.4	1.59	0.18	44.2	48.6
10/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10/7-8	1.28	61	17.99	6.76	9.99	4.28	11.61	5.68	2.48	28.5	12.19	0.78	0.95	14.20	32.3	3.10	30.1	1.67	0.24	42.1	45.4
11/0-1	0.98	90	11.25	5.68	9.63	4.31	7.64	3.35	1.44	16.3	5.93	0.62	0.94	14.10	72.1	2.33	31.7	1.73	0.18	29.3	28.8
11/1-2	0.64	92	10.42	4.35	9.34	4.05	7.43	2.98	0.78	14.2	5.27	0.50	0.78	13.40	66.6	2.30	31.9	1.60	0.16	17.0	19.0
11/2-3	1.18	95	9.47	4.30	7.65	3.58	6.86	2.44	0.74	14.2	5.07	0.60	0.81	13.42	66.7	2.32	34.9	1.67	0.14	13.1	15.2
11/3-4	0.82	99	8.63	3.40	7.91	4.33	6.54	2.46	0.62	12.7	4.56	0.62	0.59	13.21	70.8	2.21	33.7	1.69	0.20	8.9	10.0
11/4-5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11/5-6	0.57	99	8.86	5.04	8.61	4.18	11.32	4.06	0.72	12.6	4.47	0.66	0.75	13.22	73.2	2.01	33.1	1.78	0.23	7.6	8.7
11/6-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11/7-8	0.89	98	9.71	3.46	8.30	4.54	6.70	2.89	0.47	12.8	4.56	0.40	0.71	13.22	67.0	2.28	34.8	1.69	0.19	8.2	9.7

ND not determined

B5.1.SEDIMENT TRAPS - DEEP STATION

Major element concentrations and dry weight (salt-free)

Sample & Depth	Total dry wt. (g)	Si (wt.%)	Al (wt.%)	Fe (wt.%)	Mg (wt.%)	Ca (wt.%)	Na (wt.%)	K (wt.%)	Ti (wt.%)	Mn (wt.%)	P (wt.%)	Org-C (wt.%)	N (wt.%)	C/N Ratio	Salt Content (wt.%)
ST1-30m	1.75	20.7	5.4	3.3	1.1	1.7	3.7	1.3	0.23	0.23	0.16	8.7	0.59	17.2	25.4
ST2-5m	1.56	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	31.7	7.44	5.0	35.0
ST3-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST4-5m	0.67	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.4	1.15	8.6	44.7
ST5-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST6-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST7-20m	0.39	5.4	3.2	2.0	2.7	0.6	7.5	0.2	0.00	0.03	0.21	10.0	1.06	11.0	69.7
ST8-20m	0.78	6.6	1.9	13.8	1.3	1.4	4.8	0.7	0.17	0.08	0.23	8.3	0.80	12.1	61.9
ST1-85m	8.17	18.8	5.9	4.6	1.6	2.2	2.8	1.4	0.31	0.42	0.24	10.4	0.74	16.4	21.2
ST2-60m	3.16	20.1	3.3	2.6	0.9	0.6	1.7	0.7	0.17	0.03	0.32	15.9	2.08	8.9	24.6
ST3-60m	0.62	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	23.5	2.72	10.1	29.2
ST4-60m	0.62	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.1	1.60	7.4	52.1
ST5-60m	4.96	18.8	6.0	4.2	1.9	1.6	6.3	0.9	0.20	0.20	0.24	11.5	1.10	12.1	33.7
ST6-60m	3.86	17.1	5.0	5.0	1.6	1.5	5.1	1.0	0.26	0.25	0.22	10.9	0.74	17.1	33.4
ST7-60m	1.78	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	11.6	0.85	15.9	30.4
ST8-60m	1.96	12.4	3.9	6.9	1.6	0.9	6.3	0.4	0.26	0.21	0.17	8.9	0.59	17.5	56.0
ST9-60m	4.13	22.9	7.3	7.7	1.9	1.9	1.7	1.8	0.47	0.16	0.17	2.3	0.06	44.9	3.5
ST10-60m	5.23	21.4	7.1	5.9	1.9	1.9	2.6	1.8	0.45	0.20	0.21	7.3	0.50	17.1	5.7
ST11-60m	1.43	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.2	1.18	9.2	59.2
ST12-60m	4.75	26.8	7.1	5.0	2.0	1.7	2.3	1.7	0.39	0.12	0.22	5.4	0.46	13.7	8.6
ST1-145m	13.58	19.2	6.4	5.3	1.8	1.8	2.8	1.6	0.34	1.95	0.23	9.4	0.58	18.8	14.0
ST2-135m	10.46	21.0	5.1	4.0	1.4	1.3	2.2	1.4	0.28	0.92	0.39	10.4	1.01	12.0	14.6
ST3-135m	7.12	21.2	6.7	4.7	1.7	1.7	2.0	1.7	0.35	1.63	0.23	8.8	0.65	15.8	7.1
ST4-135m	4.73	20.6	6.2	5.2	1.7	1.6	2.0	1.6	0.34	1.43	0.25	9.1	0.67	15.9	9.2
ST5-135m	16.24	19.7	5.8	5.3	1.7	1.4	3.4	1.3	0.30	1.24	0.23	8.5	0.59	16.9	22.4
ST6-135m	10.88	19.0	5.9	5.2	1.7	1.5	3.6	1.4	0.33	1.08	0.23	9.8	0.69	16.5	21.4
ST7-135m	5.95	17.6	5.6	5.4	1.7	1.7	3.2	0.8	0.30	1.77	0.24	9.5	0.70	15.8	23.0
ST8-135m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST9-135m	7.72	22.0	7.2	7.1	1.9	1.7	1.9	1.8	0.43	1.47	0.18	6.0	0.34	20.5	3.2
ST10-135m	11.80	20.7	6.9	5.8	1.9	1.5	1.9	1.8	0.41	2.13	0.21	7.7	0.50	17.8	6.7
ST11-135m	5.14	19.2	6.0	5.7	1.8	1.3	2.7	1.1	0.31	2.41	0.22	8.8	0.66	15.7	26.4
ST12-135m	9.27	23.4	6.4	4.9	1.8	1.4	2.0	1.6	0.37	1.45	0.26	7.1	0.63	13.3	8.9
average surficial sediment conc.		23.0	7.3	5.4	1.8	1.1	1.9	1.9	0.42	0.57	0.18	5.6	0.44	10.8	11.3

NS no sample
ND not determined

B5.2.SEDIMENT TRAPS - DEEP STATION
Major elements (salt-free) ratioed to Al

Sample & Depth	Si/Al	Fe/Al	Mg/Al	Ca/Al	Na/Al	K/Al	Ti/Al	Mn/Al	P/Al	org-C Al	N/Al	210-Pb/Al
ST1-30m	3.81	0.60	0.20	0.31	0.68	0.25	0.04	0.04	0.03	1.59	0.108	0.0765
ST2-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST3-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST4-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST6-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST7-20m	1.65	0.61	0.84	0.19	2.30	0.06	0.00	0.01	0.06	3.08	0.326	0.0185
ST8-20m	3.40	7.14	0.66	0.74	2.47	0.36	0.09	0.04	0.12	4.32	0.416	0.0542
ST1-85m	3.18	0.79	0.26	0.38	0.48	0.23	0.05	0.07	0.04	1.76	0.125	0.0775
ST2-60m	6.14	0.79	0.26	0.20	0.53	0.22	0.05	0.01	0.10	4.88	0.637	0.0731
ST3-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST4-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-60m	3.14	0.70	0.32	0.26	1.05	0.15	0.03	0.03	0.04	1.91	0.184	0.0468
ST6-60m	3.39	1.00	0.32	0.29	1.00	0.20	0.05	0.05	0.04	2.16	0.147	0.0654
ST7-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST8-60m	3.17	1.76	0.41	0.22	1.62	0.10	0.07	0.05	0.04	2.27	0.151	0.0581
ST9-60m	3.16	1.06	0.26	0.26	0.23	0.25	0.06	0.02	0.02	0.31	0.008	0.0439
ST10-60m	3.01	0.84	0.26	0.27	0.36	0.25	0.06	0.03	0.03	1.03	0.070	0.0762
ST11-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST12-60m	3.77	0.71	0.28	0.24	0.33	0.23	0.06	0.02	0.03	0.76	0.065	0.0307
ST1-145m	3.01	0.83	0.28	0.28	0.45	0.25	0.05	0.31	0.04	1.47	0.091	0.0623
ST2-135m	4.09	0.78	0.27	0.26	0.42	0.28	0.05	0.18	0.08	2.03	0.197	0.0573
ST3-135m	3.17	0.71	0.25	0.25	0.31	0.26	0.05	0.24	0.03	1.32	0.098	0.0559
ST4-135m	3.30	0.83	0.27	0.25	0.31	0.26	0.05	0.23	0.04	1.46	0.107	0.0527
ST5-135m	3.37	0.91	0.29	0.25	0.59	0.22	0.05	0.21	0.04	1.46	0.101	0.0474
ST6-135m	3.24	0.88	0.28	0.26	0.61	0.24	0.06	0.18	0.04	1.67	0.118	0.0554
ST7-135m	3.16	0.97	0.31	0.31	0.57	0.15	0.05	0.32	0.04	1.70	0.126	0.0602
ST8-135m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST9-135m	3.08	1.00	0.27	0.23	0.27	0.26	0.06	0.21	0.03	0.84	0.048	0.0422
ST10-135m	2.99	0.84	0.27	0.22	0.28	0.26	0.06	0.31	0.03	1.11	0.073	0.0644
ST11-135m	3.22	0.95	0.29	0.22	0.46	0.18	0.05	0.40	0.04	1.48	0.110	0.0496
ST12-135m	3.64	0.76	0.28	0.22	0.32	0.24	0.06	0.23	0.04	1.11	0.098	0.0438

NS no sample
ND not determined

B5.3.SEDIMENT TRAPS - DEEP STATION

Element fluxes (salt-free)

Sample & Depth	Total dry wt. (g/m2/d)	Si (mg/m2/d)	Al (mg/m2/d)	Fe (mg/m2/d)	Mg (mg/m2/d)	Ca (mg/m2/d)	Na (mg/m2/d)	K (mg/m2/d)	Ti (mg/m2/d)	Mn (mg/m2/d)	P (mg/m2/d)	Org-C (mg/m2/d)	N (mg/m2/d)	210-Pb flux (Bq/m2/d)
ST1-30m	0.308	63.8	16.7	10.1	3.4	5.2	11.5	4.1	0.70	0.69	0.49	26.7	1.8	0.128
ST2-5m	0.669	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	211.9	49.8	0.017
ST3-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST4-5m	0.329	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	27.6	3.8	0.027
ST5-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST6-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST7-20m	0.177	9.5	5.8	3.5	4.9	1.1	13.3	0.4	0.00	0.06	0.37	17.7	1.9	0.011
ST8-20m	0.334	21.9	6.4	45.9	4.2	4.8	15.9	2.3	0.58	0.26	0.75	27.8	2.7	0.035
ST1-85m	1.435	269.3	84.8	66.6	22.3	32.1	40.3	19.9	4.5	6.1	3.5	148.9	10.6	0.657
ST2-60m	1.354	271.8	44.3	34.9	11.7	8.7	23.5	9.6	2.2	0.5	4.3	215.9	28.2	0.324
ST3-60m	0.323	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	75.9	8.8	0.072
ST4-60m	0.304	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	30.7	4.9	0.045
ST5-60m	1.230	231.7	73.8	51.9	23.4	19.2	77.2	11.3	2.5	2.5	2.9	140.9	13.6	0.346
ST6-60m	1.706	291.7	86.1	86.0	27.8	24.9	86.2	16.8	4.4	4.3	3.7	186.0	12.7	0.563
ST7-60m	0.810	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	94.2	6.9	0.284
ST8-60m	0.839	103.7	32.7	57.6	13.5	7.2	52.9	3.4	2.1	1.7	1.4	74.3	5.0	0.190
ST9-60m	1.537	352.7	111.6	118.3	28.6	28.9	25.4	28.0	7.2	2.5	2.6	34.7	0.9	0.490
ST10-60m	1.255	268.5	89.2	74.6	23.4	23.6	32.0	22.4	5.6	2.5	2.6	91.5	6.2	0.679
ST11-60m	0.577	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	53.3	6.8	0.080
ST12-60m	2.689	719.9	190.8	135.1	53.6	45.7	63.1	44.8	10.5	3.3	5.9	145.9	12.4	0.585
ST1-145m	2.385	457.0	151.9	126.0	42.0	42.5	67.9	38.2	8.2	46.5	5.4	223.3	13.9	0.946
ST2-135m	4.483	943.1	230.7	180.7	63.4	59.8	98.0	64.8	12.6	41.2	17.6	467.7	45.5	1.322
ST3-135m	3.733	791.1	249.3	176.0	63.1	62.9	76.4	64.6	13.0	61.0	8.7	329.4	24.3	1.395
ST4-135m	2.309	475.1	144.1	119.8	38.3	35.9	45.1	37.8	7.8	33.1	5.8	210.5	15.5	0.760
ST5-135m	4.030	794.6	235.4	213.7	68.4	57.7	138.1	51.6	12.1	49.9	9.4	343.3	23.7	1.116
ST6-135m	4.812	915.2	282.3	248.9	80.0	73.5	173.6	67.3	15.7	51.8	11.3	470.4	33.3	1.563
ST7-135m	2.717	478.4	151.6	147.3	47.4	47.0	86.0	22.4	8.1	48.0	6.5	257.5	19.0	0.912
ST8-135m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST9-135m	2.876	633.6	206.0	205.5	55.1	47.9	56.0	52.5	12.4	42.2	5.2	172.3	9.8	0.870
ST10-135m	2.831	587.1	196.3	164.4	54.0	43.5	54.3	50.2	11.7	60.2	5.9	217.9	14.3	1.264
ST11-135m	2.078	399.7	124.3	118.5	36.4	27.4	57.1	22.5	6.5	50.2	4.6	183.4	13.6	0.616
ST12-135m	5.248	1229.5	337.7	258.2	94.7	74.5	106.7	82.4	19.2	76.1	13.4	374.8	32.9	1.479

NS no sample
ND not determined

B5.4.SEDIMENT TRAPS - DEEP STATION

Trace element concentrations (salt-free)

Sample & Depth	Sc conc. (ppm)	Ba conc. (ppm)	V conc. (ppm)	La conc. (ppm)	Ce conc. (ppm)	Nd conc. (ppm)	Cr conc. (ppm)	Ni conc. (ppm)	Cu conc. (ppm)	Zn conc. (ppm)	Pb conc. (ppm)	Th conc. (ppm)	U conc. (ppm)	Rb conc. (ppm)	Sr conc. (ppm)	Y conc. (ppm)	Zr conc. (ppm)	Nb conc. (ppm)	Mo conc. (ppm)	I conc. (ppm)	Br conc. (ppm)
ST1-30m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST2-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST3-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST4-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST6-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST7-20m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST8-20m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST1-85m	11	339	113	38	82	30	49	24	4	366	100	4	2	103	359	17	119	10	2	392	560
ST2-60m	2	168	49	21	36	21	18	17	-13	259	51	0	3	65	184	6	61	7	3	124	361
ST3-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST4-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-60m	7	165	62	26	44	22	14	14	-24	288	76	1	1	99	320	10	83	9	5	322	699
ST6-60m	8	199	70	24	41	15	20	16	-24	463	78	1	1	99	353	13	109	9	5	310	555
ST7-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST8-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST9-60	10	642	108	50	127	47	112	66	70	634	342	5	0	92	277	33	245	13	5	174	259
ST10-60	12	514	111	45	122	45	78	45	36	223	78	11	2	94	305	29	188	13	4	148	364
ST11-60	4	244	49	20	65	20	17	39	-35	243	62	-12	-15	109	563	3	88	11	11	143	940
ST12-60	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST1-145	12	401	153	55	100	37	68	36	11	410	101	7	3	100	342	21	115	10	7	511	446
ST2-135	7	271	99	30	64	25	48	25	0	210	74	5	2	80	243	16	91	9	4	277	287
ST3-135	11	365	141	43	84	33	68	42	15	231	84	8	4	90	290	21	109	10	3	441	438
ST4-135	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-135	10	258	98	32	74	30	41	22	-8	236	80	4	2	97	319	17	104	9	4	445	445
ST6-135	8	308	103	30	63	26	46	24	-6	262	84	5	5	97	324	18	112	11	5	376	437
ST7-135	9	250	101	32	66	26	38	23	-10	240	86	4	4	98	346	18	103	10	5	445	451
ST8-135	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST9-135	12	597	134	53	127	49	84	55	61	292	398	7	0	93	292	31	232	13	5	242	267
ST10-135	9	504	141	54	120	42	78	48	37	226	82	9	1	93	316	29	147	12	8	331	368
ST11-135	4	353	108	39	84	27	57	33	8	240	76	4	0	97	363	22	106	10	10	402	565
ST12-135	11	439	120	48	99	40	80	47	31	199	66	7	-0	86	277	25	158	11	5	292	382

NS no sample
ND not determined

B5.5.SEDIMENT TRAPS - DEEP STATION

Trace element (salt-free) ratio to Al

Sample & Depth	Sc/Al ratio (x10 -4)	Ba/Al ratio (x10 -4)	V/Al ratio (x10 -4)	La/Al ratio (x10 -4)	Ce/Al ratio (x10 -4)	Nd/Al ratio (x10 -4)	Cr/Al ratio (x10 -4)	Ni/Al ratio (x10 -4)	Cu/Al ratio (x10 -4)	Zn/Al ratio (x10 -4)	Pb/Al ratio (x10 -4)	Th/Al ratio (x10 -4)	U/Al ratio (x10 -4)	Rb/Al ratio (x10 -4)	Sr/Al ratio (x10 -4)	Y/Al ratio (x10 -4)	Zr/Al ratio (x10 -4)	Nb/Al ratio (x10 -4)	Mo/Al ratio (x10 -4)	I/Al ratio (x10 -4)	Br/Al ratio (x10 -4)
ST1-30m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST2-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST3-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST4-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST6-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST7-20m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST8-20m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST1-85m	1.8	57.4	19.1	6.4	14.0	5.1	8.4	4.1	0.7	61.9	16.9	0.7	0.3	17.5	60.8	2.9	20.1	1.7	0.4	66.3	94.8
ST2-60m	0.6	51.2	15.0	6.5	11.1	6.4	5.6	5.4	-4.0	79.2	15.6	0.1	0.9	20.0	56.3	1.9	18.7	2.2	0.8	38.0	110.4
ST3-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST4-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-60m	1.1	27.5	10.3	4.4	7.3	3.6	2.4	2.4	-4.1	48.0	12.7	0.2	0.1	16.6	53.4	1.6	13.9	1.5	0.8	53.7	116.5
ST6-60m	1.5	39.4	13.9	4.8	8.2	3.0	3.9	3.2	-4.9	91.8	15.4	0.3	0.1	19.7	70.0	2.5	21.6	1.9	0.9	61.4	110.0
ST7-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST8-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST9-60	1.3	88.4	14.9	6.9	17.4	6.4	15.5	9.1	9.7	87.3	47.1	0.7	0.0	12.7	38.1	4.5	33.8	1.8	0.6	24.0	35.7
ST10-60	1.6	72.4	15.6	6.3	17.1	6.3	11.0	6.3	5.0	31.4	10.9	1.5	0.2	13.2	43.0	4.1	26.5	1.9	0.6	20.8	51.2
ST11-60	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST12-60	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST1-145	1.8	63.0	24.1	8.6	15.7	5.8	10.7	5.6	1.8	64.4	15.9	1.1	0.5	15.7	53.8	3.3	18.1	1.6	1.1	80.3	70.0
ST2-135	1.3	52.7	19.1	5.8	12.5	4.8	9.3	4.9	0.1	40.8	14.5	0.9	0.3	15.6	47.2	3.2	17.7	1.8	0.7	53.9	55.8
ST3-135	1.7	54.7	21.2	6.5	12.5	4.9	10.1	6.3	2.3	34.6	12.5	1.2	0.6	13.5	43.4	3.1	16.3	1.5	0.5	66.0	65.6
ST4-135	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-135	1.8	44.2	16.8	5.4	12.7	5.2	7.0	3.8	-1.3	40.4	13.7	0.7	0.4	16.7	54.7	2.8	17.8	1.6	0.7	76.2	76.1
ST6-135	1.4	52.6	17.5	5.1	10.8	4.5	7.8	4.2	-1.1	44.7	14.3	0.9	0.8	16.5	55.3	3.1	19.0	1.9	0.8	64.0	74.5
ST7-135	1.6	44.9	18.1	5.7	11.8	4.7	6.8	4.1	-1.8	43.1	15.5	0.7	0.6	17.5	62.0	3.3	18.4	1.8	0.8	79.8	80.7
ST8-135	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST9-135	1.7	83.4	18.7	7.4	17.8	6.9	11.8	7.7	8.5	40.8	55.5	0.9	0.0	13.0	40.8	4.4	32.4	1.8	0.7	33.8	37.3
ST10-135	1.3	72.7	20.4	7.8	17.3	6.1	11.3	6.9	5.3	32.6	11.8	1.3	0.1	13.4	45.6	4.1	21.2	1.7	1.2	47.8	53.1
ST11-135	0.7	59.1	18.1	6.5	14.1	4.6	9.5	5.6	1.3	40.2	12.6	0.7	0.0	16.1	60.7	3.6	17.8	1.7	1.7	67.2	94.5
ST12-135	1.8	68.2	18.6	7.5	15.4	6.2	12.4	7.3	4.7	31.0	10.2	1.1	-0.1	13.4	43.1	3.9	24.6	1.7	0.8	45.4	59.4

NS no sample
ND not determined

B5.6.SEDIMENT TRAPS - DEEP STATION

Trace element flux

Sample & Depth	Sc flux (mg/m2/d)	Ba flux	V flux (mg/m2/d)	La flux	Ce flux (mg/m2/d)	Nd flux	Cr flux (mg/m2/d)	Ni flux	Cu flux (mg/m2/d)	Zn flux	Pb flux (mg/m2/d)	Th flux	U flux (mg/m2/d)	Rb flux	Sr flux (mg/m2/d)	Y flux	Zr flux (mg/m2/d)	Nb flux	Mo flux	I flux (mg/m2/d)	Br flux
ST1-30m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST2-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST3-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST4-5m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST6-5m	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST7-20m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST8-20m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST1-85m	0.015	0.487	0.162	0.054	0.118	0.043	0.071	0.035	0.006	0.525	0.143	0.006	0.002	0.148	0.515	0.024	0.170	0.014	0.003	0.562	0.804
ST2-60m	0.003	0.227	0.066	0.029	0.049	0.028	0.025	0.024	-0.018	0.351	0.069	0.000	0.004	0.089	0.249	0.008	0.083	0.010	0.004	0.168	0.489
ST3-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST4-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-60m	0.008	0.203	0.076	0.032	0.054	0.027	0.018	0.017	-0.030	0.354	0.094	0.002	0.001	0.122	0.394	0.012	0.103	0.011	0.006	0.396	0.860
ST6-60m	0.013	0.339	0.120	0.041	0.070	0.026	0.034	0.028	-0.042	0.790	0.133	0.002	0.001	0.169	0.602	0.022	0.186	0.016	0.008	0.528	0.947
ST7-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST8-60m	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST9-60	0.015	0.987	0.167	0.078	0.195	0.072	0.173	0.101	0.108	0.974	0.526	0.008	0.000	0.141	0.425	0.050	0.377	0.020	0.007	0.267	0.399
ST10-60	0.015	0.646	0.139	0.056	0.153	0.056	0.098	0.057	0.045	0.280	0.097	0.014	0.002	0.118	0.383	0.036	0.236	0.017	0.005	0.186	0.457
ST11-60	0.003	0.140	0.028	0.012	0.037	0.011	0.010	0.023	-0.020	0.140	0.036	-0.007	-0.008	0.063	0.325	0.002	0.050	0.007	0.007	0.082	0.542
ST12-60	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST1-145	0.028	0.957	0.365	0.131	0.238	0.088	0.162	0.085	0.027	0.978	0.241	0.016	0.007	0.239	0.817	0.051	0.274	0.024	0.017	1.219	1.063
ST2-135	0.030	1.217	0.442	0.133	0.287	0.112	0.215	0.112	0.002	0.940	0.334	0.022	0.008	0.360	1.088	0.073	0.408	0.040	0.016	1.243	1.288
ST3-135	0.041	1.363	0.528	0.161	0.313	0.121	0.252	0.156	0.057	0.862	0.312	0.030	0.016	0.337	1.081	0.077	0.405	0.037	0.013	1.645	1.634
ST4-135	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST5-135	0.042	1.041	0.395	0.128	0.300	0.122	0.165	0.090	-0.031	0.952	0.323	0.017	0.010	0.392	1.287	0.067	0.418	0.037	0.017	1.794	1.792
ST6-135	0.039	1.484	0.494	0.145	0.305	0.127	0.219	0.118	-0.031	1.263	0.403	0.026	0.022	0.467	1.560	0.086	0.537	0.054	0.022	1.807	2.104
ST7-135	0.024	0.680	0.274	0.087	0.180	0.071	0.104	0.062	-0.027	0.653	0.235	0.010	0.010	0.265	0.940	0.050	0.279	0.027	0.012	1.209	1.224
ST8-135	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST9-135	0.036	1.718	0.385	0.152	0.367	0.141	0.242	0.158	0.176	0.841	1.144	0.019	0.000	0.267	0.840	0.090	0.668	0.038	0.014	0.695	0.768
ST10-135	0.026	1.427	0.400	0.153	0.340	0.119	0.222	0.135	0.104	0.639	0.233	0.026	0.002	0.263	0.895	0.081	0.416	0.034	0.023	0.938	1.042
ST11-135	0.009	0.734	0.225	0.081	0.175	0.057	0.118	0.069	0.016	0.499	0.157	0.008	0.001	0.201	0.754	0.045	0.221	0.021	0.022	0.836	1.174
ST12-135	0.060	2.304	0.628	0.252	0.520	0.208	0.418	0.245	0.160	1.046	0.344	0.038	-0.002	0.451	1.456	0.130	0.830	0.058	0.028	1.533	2.005

NS no sample
ND not determined

6.1.1. LOCH ETIVE - DEEP STATION
CTD Results 21st November 1990

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.5	6.3	6.1	4.76	7.8	0.94	0.2
1.0	7.4	9.6	7.44	7.7	0.99	0.0
1.5	8.1	12.4	9.57	7.3	0.96	0.0
2.0	8.6	14.5	11.16	7.1	0.95	0.0
2.5	9.0	15.9	12.21	7.0	0.96	0.1
3.0	9.2	16.2	12.42	6.9	0.95	0.1
3.5	9.5	17.2	13.16	7.0	0.97	0.1
4.1	9.6	17.6	13.46	6.8	0.96	0.1
4.5	9.6	17.9	13.69	6.9	0.97	0.1
5.0	9.5	18.1	13.86	6.8	0.96	0.1
5.5	9.5	18.9	14.48	6.7	0.94	0.0
6.0	9.6	19.5	14.93	6.6	0.94	0.0
6.5	9.7	19.9	15.23	6.7	0.96	0.0
7.0	9.8	20.7	15.84	6.6	0.96	0.0
7.5	9.9	21.2	16.22	6.4	0.93	0.0
8.1	10.1	22.1	16.89	6.3	0.91	0.0
8.6	10.1	22.2	16.97	6.2	0.90	0.0
9.0	10.2	22.1	16.87	6.3	0.93	0.0
9.5	10.2	22.2	16.95	6.2	0.91	0.0
10.0	10.2	22.4	17.11	6.3	0.93	0.0
11.0	10.3	22.7	17.32	6.4	0.94	0.0
12.0	10.6	23.0	17.51	6.3	0.94	0.0
13.0	10.8	23.3	17.72	6.2	0.93	0.0
14.0	11.0	23.4	17.76	6.0	0.91	0.0
15.0	11.1	23.6	17.90	6.0	0.91	0.0
20.0	10.7	24.1	18.35	6.2	0.93	0.0
25.0	10.8	25.4	19.35	5.7	0.86	0.0
30.0	11.1	25.4	19.30	5.0	0.76	0.0
35.0	11.5	26.2	19.85	4.0	0.62	0.0
40.0	11.7	27.0	20.44	4.3	0.67	0.0
45.0	11.6	27.1	20.53	4.2	0.66	0.0
50.0	11.4	27.2	20.64	4.1	0.64	0.0
55.0	11.1	27.3	20.77	4.0	0.62	0.0
60.0	10.9	27.4	20.88	3.9	0.60	0.0
65.0	10.7	27.5	20.99	3.8	0.58	0.0
70.0	10.6	27.5	21.01	3.6	0.55	0.0
75.0	10.5	27.5	21.02	3.5	0.53	0.0
80.0	10.4	27.6	21.12	3.5	0.53	0.0
85.0	10.3	27.6	21.13	3.3	0.50	0.0
90.0	10.3	27.6	21.13	3.2	0.48	0.0
94.5	10.3	27.6	21.13	3.1	0.47	0.0
99.8	10.3	27.6	21.13	3.0	0.45	0.0
104.5	10.2	27.6	21.15	3.0	0.45	0.0
109.5	10.2	27.7	21.23	3.0	0.45	0.0
114.5	10.2	27.7	21.23	3.0	0.45	0.0
0-10m	9.3	17.8	13.66	Inventory		
10-60m	11.2	26.0	19.78			
60-120m	10.4	27.6	21.12			

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6.1.2. LOCH ETIVE - DEEP STATION
CTD Results 12th December 1990

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	Current Velocity (cm/s)
0.5	8.1	20.0	15.51	8.0	0.0
1.0	8.5	21.9	16.95	8.4	0.0
1.5	8.7	22.2	17.16	8.7	0.0
2.0	8.9	23.7	18.30	8.8	0.0
2.5	9.0	23.7	18.29	9.2	0.0
3.0	9.1	23.6	18.19	9.5	0.0
3.5	9.0	23.8	18.36	9.9	0.0
4.5	9.1	23.9	18.43	10.0	0.0
5.5	9.9	24.3	18.63	9.9	0.2
6.5	9.9	24.4	18.71	9.7	0.2
7.0	10.0	24.5	18.77	9.6	0.2
8.0	10.1	24.5	18.75	9.4	0.2
9.0	10.1	24.4	18.68	9.3	0.2
10.0	10.2	24.7	18.89	9.1	0.2
11.0	10.3	24.7	18.88	8.9	0.2
12.0	10.3	24.6	18.80	8.9	0.2
13.0	10.3	24.7	18.88	8.7	0.1
14.0	10.1	24.8	18.99	8.4	0.0
15.0	10.0	24.7	18.92	8.0	0.0
16.0	9.9	24.8	19.02	7.4	0.0
17.0	9.6	24.7	18.98	6.8	0.0
18.0	9.5	24.8	19.07	6.3	0.0
19.0	9.4	24.9	19.17	5.9	0.0
20.0	9.2	24.9	19.20	5.7	0.1
25.0	8.9	25.3	19.55	5.4	0.1
30.0	8.8	25.4	19.64	5.2	0.1
35.0	8.9	25.7	19.86	4.9	0.1
40.0	8.9	25.8	19.94	4.7	0.0
45.0	9.2	26.2	20.21	4.5	0.0
50.0	11.2	27.1	20.60	4.4	0.0
55.5	11.2	27.4	20.83	4.4	0.0
60.0	11.1	27.4	20.85	4.3	0.0
64.9	10.9	27.5	20.96	4.4	0.0
69.5	10.7	27.6	21.07	4.5	0.0
74.5	10.6	27.6	21.09	4.5	0.0
79.5	10.5	27.6	21.10	4.5	0.0
84.5	10.4	27.7	21.20	4.6	0.0
89.5	10.4	27.7	21.20	4.9	0.0
95.0	10.3	27.6	21.13	4.8	0.0
99.5	10.3	27.6	21.13	4.7	0.0
104.8	10.3	27.7	21.21	4.6	0.0
110.0	10.3	27.6	21.13	4.5	0.0
115.0	10.3	27.6	21.13	4.5	0.0
120.0	10.3	27.7	21.21	4.4	0.0
124.5	10.2	27.7	21.23	4.4	0.0
0-10m	9.5	23.8	18.28	Inventory	
10-60m	9.8	26.0	19.95		
60-120m	10.4	27.6	21.14		

* Oxygen electrode assumed to be inaccurate - results not used.

6.1.3. LOCH ETIVE - DEEP STATION
CTD Results 6th February 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	Sigma-t (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
1.0	4.9	20.0	15.81	7.6	0.98	0.3
1.5	5.0	19.9	15.73	7.6	0.98	0.3
2.0	5.0	20.0	15.81	7.6	0.98	0.3
3.0	5.1	20.7	16.35	7.5	0.96	0.1
4.0	5.3	21.3	16.81	7.5	0.97	0.1
5.0	5.4	21.6	17.04	7.5	0.97	0.1
6.0	5.5	21.7	17.11	7.3	0.97	0.1
7.0	5.6	21.9	17.26	7.3	0.97	0.2
8.0	5.3	22.1	17.44	7.2	0.95	0.2
9.0	5.6	22.3	17.57	7.2	0.95	0.1
10.0	5.6	22.4	17.65	7.3	0.97	0.0
11.0	5.4	22.7	17.91	7.2	0.95	0.0
12.0	5.4	22.7	17.91	7.3	0.97	0.0
13.0	5.4	23.1	18.22	7.3	0.97	0.1
14.0	5.6	23.4	18.44	7.3	0.97	0.0
15.0	5.6	23.7	18.68	7.2	0.95	0.0
16.0	5.7	23.7	18.67	7.2	0.96	0.1
17.0	5.9	23.9	18.81	7.1	0.94	0.1
18.0	6.0	24.0	18.87	6.8	0.92	0.1
19.0	6.1	24.1	18.94	6.8	0.92	0.1
20.0	6.2	24.2	19.01	6.8	0.92	0.1
25.0	6.8	25.0	19.58	6.8	0.93	0.0
30.0	7.3	25.2	19.68	6.5	0.91	0.0
35.0	8.3	25.6	19.86	6.3	0.89	0.0
40.0	9.9	26.1	20.03	5.4	0.81	0.0
45.0	10.2	26.6	20.37	5.0	0.76	0.0
50.0	10.5	26.9	20.56	4.6	0.70	0.0
55.0	10.6	27.1	20.70	4.2	0.64	0.0
60.0	10.7	27.4	20.91	3.9	0.60	0.0
65.0	10.7	27.5	20.99	3.7	0.56	0.0
70.0	10.7	27.6	21.07	3.5	0.54	0.0
75.0	10.6	27.6	21.09	3.4	0.52	0.0
80.0	10.5	27.6	21.10	3.3	0.49	0.0
85.0	10.5	27.7	21.18	3.3	0.49	0.0
90.0	10.5	27.7	21.18	3.1	0.47	0.0
94.5	10.4	27.7	21.20	3.1	0.47	0.0
99.5	10.4	27.7	21.20	3.0	0.45	0.0
104.5	10.4	27.7	21.20	3.0	0.45	0.0
109.5	10.4	27.6	21.12	3.0	0.45	0.0
114.5	10.4	27.7	21.20	3.0	0.45	0.0
120.0	10.3	27.7	21.21	3.0	0.45	0.0
124.5	10.2	27.7	21.23	3.0	0.45	0.0
0-10m	5.3	21.4	16.89	7.4	Inventory	
10-60m	8.6	25.7	19.88	5.7		
60-120m	10.5	27.7	21.15	3.2		

6.1.4. LOCH ETIVE - DEEP STATION
CTD Results 22nd March 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
1.0	6.7	3.4	2.61	8.2	0.98	0.0
1.5	6.7	3.4	2.61	8.0	0.95	0.0
1.9	6.7	3.8	2.93	7.9	0.95	0.1
2.5	6.0	5.1	3.99	7.8	0.93	0.1
3.5	5.7	8.3	6.53	7.6	0.92	0.2
4.5	5.9	11.9	9.36	7.4	0.93	0.4
5.5	6.0	18.1	14.23	7.1	0.92	0.2
6.5	6.1	19.0	14.93	6.9	0.90	0.1
7.5	6.1	21.5	16.90	6.5	0.86	0.1
8.5	6.2	22.5	17.67	6.5	0.87	0.1
9.5	6.2	22.9	17.99	6.5	0.87	0.1
10.5	6.2	23.3	18.30	6.4	0.86	0.1
11.5	6.3	23.8	18.69	6.3	0.85	0.0
12.5	6.3	24.2	19.00	6.3	0.85	0.0
13.5	6.3	24.6	19.32	6.2	0.84	0.0
14.5	6.3	24.9	19.55	6.3	0.85	0.1
15.5	6.3	25.1	19.71	6.2	0.85	0.1
16.5	6.3	25.2	19.79	6.2	0.85	0.1
17.5	6.4	25.5	20.01	6.0	0.82	0.1
18.5	6.5	25.6	20.08	5.9	0.81	0.1
19.5	6.5	25.8	20.24	5.8	0.79	0.1
25.0	6.7	26.1	20.45	6.0	0.83	0.0
30.0	6.9	26.3	20.59	5.8	0.82	0.0
35.0	6.7	26.4	20.69	5.8	0.82	0.0
40.0	6.7	26.5	20.77	5.8	0.82	0.0
45.0	7.0	26.7	20.89	5.8	0.82	0.0
50.0	7.3	26.8	20.93	5.3	0.75	0.0
55.0	7.4	27.0	21.08	5.4	0.77	0.0
60.0	7.7	27.2	21.19	5.2	0.74	0.0
65.0	8.1	27.2	21.14	4.8	0.70	0.0
70.0	8.5	27.3	21.17	4.4	0.64	0.1
75.0	8.7	27.4	21.22	4.2	0.62	0.0
80.0	9.4	27.5	21.19	3.6	0.54	0.1
84.5	9.6	27.5	21.16	3.2	0.48	0.1
89.5	9.7	27.5	21.15	3.2	0.48	0.0
94.5	9.8	27.6	21.21	3.2	0.48	0.0
99.5	9.8	27.6	21.21	3.1	0.47	0.0
104.5	9.8	27.6	21.21	3.1	0.47	0.0
109.5	9.8	27.6	21.21	3.0	0.45	0.0
114.5	9.9	27.6	21.20	3.0	0.45	0.0
119.5	9.9	27.7	21.27	3.0	0.45	0.0
0-10m	6.2	13.7	10.71	Inventory		
10-60m	6.9	26.3	20.55			
60-120m	9.4	27.5	21.20			

6.1.5. LOCH ETIVE - DEEP STATION
CTD Results 18th April 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.0	7.4	7.0	5.40	7.7	0.96	0.0
1.0	7.4	7.9	6.11	7.6	0.95	0.2
2.0	7.4	9.5	7.36	7.5	0.95	0.1
3.0	7.4	11.5	8.93	7.3	0.94	0.2
4.0	7.3	12.4	9.64	7.3	0.95	0.2
5.0	7.3	13.5	10.51	7.2	0.94	0.4
6.0	7.3	13.9	10.82	7.2	0.94	0.3
7.0	7.3	14.4	11.21	7.1	0.92	0.3
8.0	7.3	15.5	12.07	7.0	0.91	0.3
9.0	7.2	16.2	12.63	7.0	0.92	0.3
9.9	7.2	17.0	13.26	7.0	0.92	0.4
10.9	7.2	19.4	15.14	6.8	0.91	0.2
12.0	7.1	20.2	15.78	6.7	0.91	0.1
13.0	7.1	20.7	16.17	6.5	0.88	0.1
14.0	7.1	21.1	16.48	6.4	0.86	0.1
15.0	7.0	21.8	17.04	6.4	0.86	0.1
16.0	7.0	22.5	17.59	6.4	0.86	0.0
17.0	7.0	22.8	17.83	6.3	0.86	0.0
18.0	7.0	22.8	17.83	6.3	0.86	0.0
19.0	6.9	23.4	18.31	6.2	0.85	0.0
20.0	6.8	24.2	18.95	6.1	0.84	0.0
25.0	7.0	25.4	19.87	5.9	0.82	0.0
29.5	7.4	26.2	20.45	5.4	0.76	0.1
35.0	7.4	26.6	20.76	5.3	0.75	0.0
40.0	7.4	26.8	20.92	5.2	0.73	0.0
45.0	7.6	26.8	20.89	5.0	0.71	0.1
50.0	7.8	27.0	21.03	4.9	0.70	0.1
55.0	8.2	27.0	20.97	4.6	0.66	0.0
60.0	8.4	27.2	21.10	4.5	0.65	0.0
65.0	8.7	27.3	21.14	4.2	0.61	0.1
70.0	8.9	27.3	21.11	4.0	0.59	0.1
75.0	9.1	27.3	21.08	3.8	0.56	0.0
79.7	9.3	27.4	21.13	3.6	0.54	0.0
84.5	9.4	27.4	21.12	3.4	0.51	0.0
89.5	9.5	27.4	21.10	3.2	0.48	0.0
94.0	9.5	27.5	21.18	3.1	0.46	0.0
99.5	9.6	27.5	21.16	3.1	0.46	0.0
0-10m	7.3	13.2	10.25	Inventory		
10-60m	7.5	25.7	20.02			
60-120m	9.3	27.4	21.13			

6.1.6. LOCH ETIVE - DEEP STATION
CTD Results 22nd May 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.0	10.6	17.6	13.32	8.0	1.14	0.0
0.5	10.6	18.4	13.94	7.9	1.14	0.1
1.0	10.5	18.6	14.11	7.7	1.12	0.1
2.0	10.5	19.7	14.97	7.7	1.12	0.0
3.0	10.2	21.3	16.25	7.5	1.09	0.0
4.0	9.1	23.1	17.80	7.3	1.04	0.0
5.0	8.8	23.6	18.24	7.3	1.04	0.0
6.0	8.7	23.8	18.40	7.3	1.04	0.0
7.0	8.7	24.3	18.79	7.3	1.04	0.0
8.0	8.6	24.7	19.12	7.3	1.04	0.0
9.0	8.4	25.0	19.38	7.2	1.03	0.0
10.0	8.3	25.0	19.39	7.2	1.03	0.0
12.0	8.1	25.2	19.58	7.1	1.01	0.0
14.0	8.0	25.3	19.67	7.0	1.00	0.0
16.0	8.1	25.4	19.73	7.0	1.00	0.0
20.0	8.3	25.9	20.10	7.0	1.00	0.0
25.0	8.6	25.9	20.06	7.1	1.03	0.0
30.0	8.7	26.0	20.12	7.3	1.06	0.0
35.0	8.7	26.1	20.20	7.4	1.07	0.0
40.0	8.7	26.3	20.36	7.3	1.06	0.0
45.0	8.7	26.4	20.44	7.0	1.01	0.0
50.0	8.7	26.6	20.59	7.0	1.03	0.0
55.0	8.7	26.6	20.59	6.6	0.97	0.0
60.0	8.7	26.7	20.67	5.7	0.84	0.0
65.0	8.8	26.9	20.81	5.0	0.74	0.0
70.0	9.0	27.0	20.86	4.5	0.66	0.0
75.0	9.3	27.2	20.97	4.0	0.59	0.0
80.0	9.4	27.3	21.04	3.8	0.57	0.0
85.0	9.4	27.3	21.04	3.6	0.54	0.0
90.0	9.5	27.3	21.02	3.6	0.54	0.0
95.0	9.5	27.3	21.02	3.4	0.51	0.0
99.5	9.5	27.3	21.02	3.3	0.49	0.0
104.5	9.6	27.3	21.01	3.3	0.49	0.0
109.5	9.6	27.3	21.01	3.2	0.48	0.0
114.5	9.6	27.3	21.01	3.2	0.48	0.0
0-10m	9.2	22.9	17.65	Inventory		
10-60m	8.6	26.2	20.27			
60-120m	9.4	27.2	20.98			

6.1.7. LOCH ETIVE - DEEP STATION
CTD Results 18th June 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.0	11.6	12.0	8.85	7.7	1.10	0.0
1.0	11.5	14.0	10.41	7.5	1.07	0.0
2.0	11.3	19.2	14.46	7.3	1.07	0.0
3.0	11.0	22.2	16.83	7.2	1.07	0.1
4.0	10.8	22.8	17.33	7.1	1.06	0.1
5.0	10.7	23.9	18.20	7.1	1.06	0.1
6.0	10.6	24.1	18.37	7.0	1.04	0.1
7.0	10.5	24.3	18.54	7.0	1.04	0.1
8.0	10.5	24.5	18.69	6.9	1.03	0.1
9.0	10.4	24.9	19.02	6.8	1.01	0.1
10.0	10.4	25.1	19.17	6.8	1.01	0.1
13.0	10.2	25.6	19.59	6.8	1.01	0.1
16.0	9.3	26.0	20.04	6.3	0.93	0.0
18.0	9.6	26.5	20.38	6.4	0.96	0.0
20.0	9.9	26.4	20.26	6.5	0.97	0.0
25.0	9.3	26.5	20.43	6.5	0.96	0.0
30.0	9.2	26.8	20.68	6.4	0.94	0.0
35.0	9.5	26.8	20.63	6.4	0.96	0.0
40.0	9.8	27.0	20.74	6.5	0.97	0.0
45.0	10.3	27.1	20.75	6.7	1.02	0.0
50.0	10.3	27.1	20.75	6.4	0.97	0.0
55.0	10.3	27.2	20.82	6.4	0.97	0.0
60.0	10.3	27.2	20.82	6.4	0.97	0.0
65.0	10.3	27.2	20.82	6.2	0.94	0.0
70.0	10.2	27.2	20.84	6.2	0.94	0.0
75.0	10.0	27.3	20.95	5.8	0.88	0.0
80.0	9.9	27.2	20.89	5.4	0.82	0.0
85.0	9.7	27.2	20.92	5.0	0.75	0.0
90.0	9.7	27.2	20.92	4.6	0.69	0.0
94.5	9.6	27.3	21.01	4.3	0.64	0.0
99.5	9.6	27.3	21.01	4.1	0.61	0.0
104.5	9.5	27.3	21.02	3.8	0.57	0.0
109.5	9.5	27.3	21.02	3.7	0.55	0.0
114.5	9.5	27.3	21.02	3.6	0.54	0.0
0-10m	10.8	21.5	16.35	Inventory		
10-60m	9.9	26.8	20.57			
60-120m	9.8	27.3	20.95			

6.1.8. LOCH ETIVE - DEEP STATION
CTD Results 17th July 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.0	14.4	10.2	7.04	6.1	0.96	0.0
1.0	14.3	13.5	9.59	6.0	0.95	0.0
1.5	14.2	15.7	11.29	6.0	0.97	0.0
2.0	13.6	16.4	11.93	6.0	0.95	0.0
2.5	13.5	17.3	12.64	5.8	0.92	0.0
3.0	13.2	19.5	14.39	5.7	0.92	0.0
3.5	13.0	20.3	15.04	5.6	0.90	0.0
4.0	12.9	21.2	15.75	5.5	0.89	0.0
4.5	12.8	21.5	16.00	5.5	0.89	0.0
5.0	12.8	21.7	16.15	5.5	0.90	0.0
6.0	12.7	22.5	16.79	5.5	0.90	0.1
7.0	12.7	23.4	17.48	5.5	0.90	0.1
8.0	12.5	23.6	17.67	5.4	0.89	0.1
9.0	12.5	23.6	17.67	5.4	0.89	0.1
10.0	12.5	24.6	18.44	5.4	0.89	0.1
11.0	12.5	24.9	18.67	5.3	0.87	0.1
12.0	12.3	25.1	18.86	5.4	0.89	0.1
14.0	12.1	25.5	19.21	5.2	0.85	0.0
16.0	12.1	25.6	19.28	5.1	0.84	0.0
18.0	12.1	25.9	19.52	5.3	0.87	0.0
20.0	11.8	26.2	19.80	5.3	0.87	0.0
25.0	11.7	26.4	19.97	5.3	0.87	0.0
30.0	10.2	26.4	20.22	5.0	0.78	0.0
35.0	10.1	26.5	20.31	4.9	0.77	0.0
40.0	9.8	26.6	20.43	4.8	0.75	0.0
45.0	10.0	26.7	20.48	4.9	0.77	0.0
50.0	9.8	26.8	20.59	4.8	0.75	0.0
55.0	9.9	27.0	20.73	4.5	0.71	0.0
60.0	9.9	27.0	20.73	4.4	0.69	0.0
65.0	9.9	27.1	20.81	4.2	0.66	0.0
70.0	9.9	27.1	20.81	4.0	0.63	0.0
75.0	9.8	27.1	20.82	3.9	0.61	0.0
79.5	9.8	27.2	20.90	3.7	0.58	0.0
84.5	9.8	27.2	20.90	3.6	0.56	0.0
89.5	9.8	27.2	20.90	3.6	0.56	0.0
94.5	9.8	27.2	20.90	3.4	0.53	0.0
99.5	9.8	27.2	20.90	3.4	0.53	0.0
104.5	9.8	27.2	20.90	3.3	0.52	0.0
109.5	9.7	27.2	20.92	3.2	0.50	0.0
0-10m	13.1	20.0	14.81	Inventory		
10-60m	10.6	26.5	20.21			
60-120m	9.8	27.2	20.88			

6.1.9. LOCH ETIVE - DEEP STATION
CTD Results 12th September 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.5	14.1	23.7	17.46	5.4	0.98	0.2
1.0	14.1	23.6	17.38	5.3	0.96	0.2
1.5	14.1	23.7	17.46	5.2	0.94	0.2
2.0	13.9	24.1	17.80	5.1	0.92	0.1
2.5	13.8	25.2	18.67	4.9	0.89	0.0
3.0	13.9	25.7	19.03	4.9	0.89	0.1
4.0	13.9	25.9	19.19	4.8	0.87	0.1
5.0	13.8	26.0	19.28	4.8	0.87	0.2
6.0	13.8	26.0	19.28	4.8	0.87	0.1
7.0	13.9	26.0	19.26	4.8	0.87	0.0
8.0	13.9	26.0	19.26	4.9	0.89	0.0
10.0	13.9	26.0	19.26	4.9	0.89	0.1
12.0	13.8	26.0	19.28	4.8	0.87	0.1
14.0	13.8	26.1	19.36	4.8	0.87	0.1
16.0	13.7	26.2	19.46	4.7	0.85	0.1
18.0	13.7	26.3	19.53	4.7	0.85	0.2
20.0	13.8	26.3	19.51	4.8	0.87	0.1
25.0	13.7	26.5	19.69	4.8	0.87	0.1
30.0	13.5	26.7	19.88	4.7	0.85	0.0
35.0	13.3	26.7	19.92	4.7	0.85	0.0
39.5	13.3	27.0	20.15	4.7	0.85	0.0
44.5	13.3	27.0	20.15	4.7	0.85	0.0
49.5	12.8	27.0	20.24	4.6	0.83	0.0
54.5	12.4	27.0	20.31	4.4	0.78	0.0
59.0	10.5	26.6	20.32	3.6	0.61	0.0
61.0	9.7	26.7	20.53	3.4	0.57	0.0
63.0	9.6	26.8	20.62	3.3	0.55	0.0
69.0	9.6	26.9	20.70	3.3	0.55	0.0
74.0	9.6	27.0	20.77	3.2	0.53	0.0
79.0	9.6	27.0	20.77	3.2	0.53	0.0
84.0	9.6	27.0	20.77	3.2	0.53	0.0
88.5	9.6	27.0	20.77	3.2	0.53	0.0
93.5	9.6	27.0	20.77	3.1	0.52	0.0
99.0	9.6	27.0	20.77	3.1	0.52	0.0
104.0	9.6	27.1	20.85	3.1	0.52	0.0
109.0	9.6	27.1	20.85	3.0	0.50	0.0
109.5	9.7	27.2	20.92	3.0	0.50	0.0
0-10m	13.9	25.5	18.87	Inventory		
10-60m	13.0	26.7	19.95			
60-120m	9.6	27.0	20.77			

6.1.10. LOCH ETIVE - DEEP STATION
CTD Results 14th October 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	Current Velocity (cm/s)
0.5	11.4	10.1	7.41		0.0
1.0	11.4	11.4	8.41		0.2
2.0	11.4	13.5	10.04		0.0
3.0	11.5	14.0	10.41		0.0
4.0	11.5	14.4	10.72		0.1
5.0	11.5	16.0	11.96		0.1
6.0	11.6	16.6	12.41		0.1
7.0	11.7	17.4	13.01		0.0
8.0	11.7	17.9	13.40		0.0
9.0	11.8	18.8	14.08		0.0
10.0	11.9	19.9	14.91		0.1
12.0	12.0	20.5	15.36		0.0
14.0	12.0	21.1	15.82		0.0
16.0	12.1	21.7	16.27		0.0
18.0	12.0	22.6	16.98		0.0
20.0	12.2	24.5	18.42		0.0
25.0	12.0	26.7	20.15		0.0
30.0					
35.0					
0-10m	11.6	15.9	11.9	Inventory	

CTD battery ran flat at 30m
Oxygen electrode functioned improperly throughout

6.1.11. LOCH ETIVE - DEEP STATION
CTD Results 13th November 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.0	6.8	3.7	2.84	6.6	0.99	0.1
1.0	6.9	4.8	3.70	6.2	0.95	0.2
1.5	6.9	4.1	3.15	6.1	0.92	0.2
2.0	6.9	4.0	3.07	6.1	0.92	0.0
3.0	6.9	4.2	3.23	6.0	0.90	0.0
4.0	6.6	4.3	3.33	6.1	0.91	0.0
5.0	6.3	4.7	3.66	6.1	0.91	0.2
6.0	6.7	5.8	4.50	6.0	0.91	0.2
7.0	7.2	8.4	6.51	6.0	0.94	0.0
8.0	8.8	15.0	11.53	5.6	0.95	0.0
9.0	10.1	19.1	14.56	5.0	0.89	0.2
10.0	10.2	19.6	14.93	4.8	0.87	0.1
12.0	10.4	20.5	15.60	4.8	0.87	0.2
14.0	11.3	22.0	16.63	4.7	0.89	0.2
16.0	11.6	22.5	16.97	4.5	0.85	0.0
18.0	11.6	23.3	17.59	4.4	0.83	0.1
20.0	11.5	23.9	18.07	4.4	0.83	0.1
25.0	11.5	24.9	18.84	4.2	0.81	0.1
30.0	11.5	26.1	19.77	3.8	0.73	0.1
35.0	11.7	26.6	20.13	3.5	0.68	0.1
40.0	12.6	27.2	20.43	3.7	0.73	0.1
45.0	12.6	27.2	20.43	3.9	0.77	0.1
49.5	12.2	27.1	20.43	3.8	0.75	0.1
54.5	11.7	27.0	20.44	3.7	0.72	0.0
59.5	11.4	27.1	20.57	3.6	0.70	0.0
64.5	11.0	27.1	20.63	3.4	0.65	0.0
69.0	10.8	27.1	20.67	3.2	0.62	0.1
74.0	10.7	27.2	20.76	3.2	0.62	0.0
79.0	10.4	27.2	20.81	3.1	0.59	0.0
83.5	10.3	27.2	20.82	3.0	0.57	0.0
88.5	10.1	27.2	20.85	2.9	0.55	0.0
93.5	10.0	27.2	20.87	2.8	0.53	0.0
98.5	9.9	27.2	20.89	2.8	0.53	0.0
104.0	9.9	27.2	20.89	2.8	0.53	0.0
109.0	9.8	27.3	20.98	2.7	0.51	0.0
113.5	9.8	27.3	20.98	2.6	0.49	0.0
0-10m	7.6	8.5	6.53	Inventory		
10-60m	11.8	25.8	19.50			
60-120m	10.2	27.2	20.83			

6.1.12. LOCH ETIVE - AIRD'S BAY
CTD Results 14th November 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	Dissolved Oxygen (ppm)	Current Velocity (cm/s)
0.0	6.9	4.8	6.3	0.0
1.0	7.0	5.1	6.1	0.0
2.0	7.1	5.7	6.0	0.1
3.0	7.2	6.3	5.9	0.2
4.0	7.5	7.5	5.9	0.2
5.0	7.8	9.6	5.8	0.1
6.0	8.3	12.1	5.6	0.2
7.0	8.6	12.5	5.5	0.2
8.0	8.8	14.6	5.4	0.1
9.0	9.0	16.0	5.3	0.0
10.0	9.4	17.5	5.2	0.1
11.0	9.7	18.5	5.0	0.1
12.0	10.1	19.5	5.0	0.1
14.0	10.4	20.9	4.8	0.1
16.0	10.5	21.5	4.7	0.1
18.0	10.6	21.9	4.7	0.2
20.0	10.6	22.4	4.7	0.1
22.0	10.6	22.9	4.6	0.1
25.0	10.6	23.7	4.6	0.0
30.0	11.1	25.2	4.6	0.0
35.0	11.5	26.4	4.4	0.1
40.0	12.6	27.4	3.9	0.0
45.0	12.8	27.6	3.7	0.0
50.0	13.0	27.7	3.4	0.0

6.1.13. LOCH ETIVE - DEEP STATION
CTD Results 12th December 1991

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.5	9.0	16.3	12.52	5.3	0.96	0.0
1.0	8.9	17.7	13.62	5.3	0.97	0.0
2.0	9.0	17.8	13.69	5.2	0.95	0.0
3.0	9.1	19.0	14.61	5.1	0.95	0.0
4.0	9.4	19.3	14.80	5.0	0.93	0.0
5.0	9.5	19.6	15.03	5.0	0.94	0.0
6.0	9.6	20.1	15.40	4.9	0.92	0.0
7.0	9.6	20.3	15.56	4.9	0.92	0.0
8.0	9.5	20.7	15.88	4.9	0.92	0.0
9.0	9.5	20.8	15.96	4.9	0.92	0.0
10.0	9.3	20.8	15.99	4.9	0.92	0.1
12.0	9.1	21.2	16.32	4.9	0.92	0.0
14.0	9.0	21.6	16.65	5.0	0.94	0.1
16.0	8.9	22.0	16.97	5.0	0.94	0.1
18.0	9.0	22.6	17.43	5.0	0.94	0.1
20.0	9.1	23.2	17.88	4.9	0.92	0.1
24.5	10.2	24.5	18.74	4.4	0.87	0.1
29.5	11.5	26.1	19.77	3.8	0.77	0.1
34.5	11.7	26.6	20.13	3.4	0.70	0.0
39.5	12.3	27.0	20.33	3.7	0.78	0.0
44.5	12.4	27.1	20.39	3.7	0.78	0.0
49.5	12.2	27.1	20.43	3.8	0.80	0.1
54.5	11.9	27.1	20.48	3.6	0.74	0.1
59.5	11.6	27.2	20.61	3.5	0.72	0.1
64.5	11.2	27.2	20.68	3.4	0.69	0.0
69.5	11.0	27.2	20.71	3.3	0.67	0.0
74.5	10.8	27.2	20.74	3.2	0.65	0.0
79.5	10.6	27.2	20.78	3.1	0.62	0.0
84.5	10.4	27.2	20.81	3.0	0.60	0.0
89.5	10.2	27.2	20.84	2.9	0.58	0.0
94.5	10.1	27.2	20.85	2.8	0.56	0.0
99.5	10.1	27.2	20.85	2.7	0.54	0.0
104.0	10.1	27.2	20.85	2.7	0.54	0.0
109.0	10.0	27.2	20.87	2.6	0.52	0.0
114.0	10.0	27.3	20.95	2.6	0.52	0.0
119.0	10.0	27.3	20.95	2.5	0.50	0.0
0-10m	9.3	19.5	15.00	Inventory		
10-60m	11.2	25.7	19.50			
60-120m	10.4	27.2	20.82			

6.1.14. LOCH ETIVE - DEEP STATION
CTD Results 24th February 1992

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.5	5.5	5.4	4.25	6.7	0.98	0.0
1.0	5.5	5.3	4.17	6.7	0.98	0.1
2.0	5.5	5.5	4.33	6.7	0.98	0.0
3.0	5.5	6.5	5.12	6.7	0.99	0.0
4.0	5.6	7.1	5.59	6.6	0.97	0.0
5.0	5.7	7.7	6.06	6.6	0.97	0.0
6.0	5.8	11.3	8.89	6.4	0.97	0.0
6.5	6.0	12.8	10.06	6.3	0.98	0.0
7.0	6.1	15.0	11.78	6.1	0.96	0.0
7.5	6.3	15.5	12.16	6.0	0.94	0.0
8.0	6.4	15.7	12.31	6.0	0.95	0.0
9.0	6.6	15.7	12.29	5.9	0.94	0.0
10.0	6.7	19.3	15.11	5.8	0.95	0.0
11.0	6.9	20.0	15.64	5.7	0.94	0.0
12.0	7.1	20.4	15.93	5.5	0.92	0.0
14.0	7.5	21.6	16.83	5.4	0.92	0.1
16.0	7.5	23.3	18.16	5.3	0.91	0.0
18.0	7.5	22.7	17.69	5.3	0.91	0.0
19.0	7.9	22.7	17.65	5.2	0.90	0.0
20.0	7.9	23.0	17.88	5.1	0.89	0.1
22.0	8.0	23.2	18.02	5.0	0.87	0.0
25.0	8.1	23.5	18.25	5.0	0.87	0.0
30.0	8.5	24.3	18.82	4.9	0.87	0.0
35.0	10.2	25.4	19.44	4.1	0.76	0.0
40.0	11.0	26.2	19.93	3.5	0.67	0.1
45.0	11.5	26.9	20.39	3.3	0.64	0.0
50.0	11.7	27.0	20.44	3.3	0.64	0.0
55.0	11.7	27.0	20.44	3.3	0.64	0.0
60.0	11.6	27.1	20.53	3.3	0.64	0.0
64.5	11.4	27.1	20.57	3.3	0.64	0.0
69.5	11.2	27.2	20.68	3.2	0.61	0.0
74.5	11.1	27.2	20.69	3.1	0.59	0.0
79.5	10.9	27.1	20.65	3.0	0.57	0.0
84.5	10.7	27.1	20.68	2.9	0.54	0.0
89.5	10.6	27.1	20.70	2.8	0.53	0.0
94.5	10.6	27.2	20.78	2.8	0.53	0.0
99.5	10.5	27.2	20.79	2.7	0.51	0.0
104.5	10.4	27.2	20.81	2.7	0.51	0.0
109.5	10.4	27.2	20.81	2.6	0.49	0.0
114.5	10.4	27.2	20.81	2.5	0.47	0.0

6.1.15. LOCH ETIVE - DEEP STATION
CTD Results 24th March 1992

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.5	6.9	1.8	1.34	6.4	1.03	0.1
1.0	6.8	2.1	1.58	6.4	1.03	0.2
2.0	6.6	2.4	1.83	6.4	1.03	0.1
3.0	6.5	3.3	2.54	6.3	1.01	0.0
4.0	6.4	4.1	3.18	6.2	1.00	0.0
5.0	6.3	8.5	6.65	6.0	0.99	0.0
6.0	6.3	9.6	7.52	5.9	0.97	0.0
7.0	6.3	11.2	8.78	5.7	0.95	0.0
8.0	6.4	12.1	9.48	5.7	0.96	0.0
9.0	6.5	13.9	10.89	5.6	0.96	0.0
10.0	6.6	15.1	11.82	5.6	0.97	0.0
15.0	6.9	18.1	14.15	5.2	0.92	0.0
20.0	8.6	23.2	17.95	4.3	0.82	0.0
25.0	9.0	23.9	18.44	3.9	0.76	0.0
30.0	9.5	24.3	18.69	3.7	0.72	0.0
35.0	9.8	25.1	19.26	3.4	0.68	0.0
40.0	10.5	26.0	19.86	3.1	0.63	0.0
45.0	11.3	26.7	20.27	2.8	0.58	0.0
50.0	11.5	27.0	20.47	2.8	0.59	0.0
55.0	11.5	27.1	20.55	2.8	0.59	0.0
60.0	11.3	27.1	20.58	2.7	0.56	0.0
64.5	11.1	27.1	20.62	2.7	0.56	0.0
69.5	11.0	27.1	20.63	2.6	0.54	0.0
74.5	10.9	27.1	20.65	2.5	0.52	0.0
79.5	10.7	27.1	20.68	2.4	0.50	0.0
84.5	10.7	27.1	20.68	2.4	0.50	0.0
89.5	10.6	27.1	20.70	2.3	0.48	0.0
94.0	10.5	27.2	20.79	2.3	0.47	0.0
99.0	10.5	27.2	20.79	2.2	0.45	0.0
104.0	10.5	27.2	20.79	2.0	0.41	0.0
109.0	10.4	27.2	20.81	2.0	0.41	0.0
114.0	10.4	27.2	20.81	2.0	0.41	0.0
0-10m	6.5	8.2	6.41	Inventory		
10-60m	10.0	24.9	19.02			
60-120m	10.7	27.1	20.72			

6.1.16. LOCH ETIVE - DEEP STATION
CTD Results 23rd April 1992

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.5	8.3	10.3	7.91	NR	NR	0.0
1.0	8.3	11.5	8.85	NR	NR	0.0
1.5	8.4	14.9	11.49	NR	NR	0.0
2.0	7.9	17.7	13.73	NR	NR	0.0
3.0	7.8	18.6	14.45	6.5	8.8	0.0
4.0	7.7	19.5	15.16	6.4	8.6	0.0
5.0	7.6	20.3	15.80	6.1	8.2	0.1
6.0	7.6	20.7	16.11	5.8	7.8	0.0
8.0	7.5	21.2	16.52	5.7	7.7	0.0
10.0	7.6	21.6	16.82	5.6	7.6	0.0
15.0	7.6	22.5	17.52	5.5	7.4	0.0
20.0	7.6	22.9	17.84	5.5	7.4	0.0
25.0	7.6	23.5	18.31	5.4	7.3	0.0
30.0	7.9	23.9	18.58	5.3	7.2	0.0
35.0	8.2	24.2	18.78	5.2	7.0	0.0
40.0	9.7	25.2	19.36	4.5	6.1	0.0
45.0	10.7	26.4	20.14	3.6	4.9	0.0
50.0	11.2	26.9	20.44	3.0	4.1	0.0
55.0	11.4	27.0	20.49	2.9	3.9	0.0
60.0	11.4	27.1	20.57	2.8	3.8	0.0
64.5	11.3	27.1	20.58	2.7	3.6	0.0
69.5	11.1	27.1	20.62	2.6	3.5	0.0
74.5	11.0	27.1	20.63	2.6	3.5	0.0
79.5	10.9	27.1	20.65	2.5	3.4	0.0
84.5	10.8	27.2	20.74	2.4	3.2	0.0
89.5	10.7	27.2	20.76	2.4	3.2	0.0
94.5	10.7	27.2	20.76	2.3	3.1	0.0
99.5	10.6	27.2	20.78	2.2	3.0	0.0
104.5	10.6	27.2	20.78	2.1	2.8	0.0
109.0	10.6	27.2	20.78	2.1	2.8	0.0
114.0	10.6	27.2	20.78	2.0	2.7	0.0
0-10m	7.7	19.2	14.92	Inventory		
10-60m	9.3	25.0	19.20			
60-120m	10.8	27.2	20.71			

NR - no results - oxygen electrode inaccurate

6.1.17. LOCH ETIVE - DEEP STATION
CTD Results 28th May 1992

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.5	12.1	18.3	13.64	6.1	1.16	0.0
1.0	12.1	18.4	13.72	6.2	1.18	0.2
2.0	12.0	18.5	13.81	NR	NR	0.2
3.0	12.0	18.6	13.89	NR	NR	0.2
4.0	11.5	18.8	14.12	NR	NR	0.2
5.0	11.0	19.2	14.51	6.0	1.12	0.1
6.0	10.9	20.0	15.14	5.8	1.08	0.0
7.0	11.1	20.9	15.81	5.8	1.08	0.1
8.0	11.3	21.2	16.01	5.8	1.10	0.0
9.0	11.1	21.4	16.20	5.7	1.08	0.0
10.0	11.0	21.6	16.37	5.6	1.06	0.1
15.0	10.3	22.3	17.01	5.5	1.03	0.0
20.0	10.1	22.7	17.35	5.4	1.01	0.2
25.0	9.2	23.3	17.95	4.8	0.88	0.1
30.0	8.9	23.6	18.22	4.6	0.83	0.1
35.0	9.1	24.0	18.51	4.2	0.77	0.0
40.0	9.7	25.0	19.20	3.9	0.73	0.0
45.0	10.6	26.0	19.84	3.3	0.64	0.0
50.0	11.1	26.5	20.15	2.7	0.53	0.0
55.0	11.3	26.8	20.35	2.6	0.51	0.0
60.0	11.3	27.0	20.51	2.6	0.51	0.0
64.5	11.2	27.0	20.52	2.6	0.51	0.0
69.5	11.1	27.0	20.54	2.5	0.49	0.0
74.5	11.1	27.0	20.54	2.4	0.47	0.0
79.5	11.0	27.0	20.56	2.3	0.45	0.0
84.5	10.9	27.0	20.57	2.3	0.45	0.0
89.5	10.8	27.0	20.59	2.2	0.43	0.0
94.0	10.8	27.1	20.67	2.1	0.41	0.0
99.0	10.8	27.1	20.67	2.0	0.39	0.0
104.0	10.7	27.1	20.68	2.0	0.39	0.0
109.0	10.8	27.1	20.67	1.9	0.37	0.0
114.0	10.7	27.1	20.68	1.9	0.37	0.0
119.0	10.7	27.1	20.68	1.8	0.35	0.0
0-10m	11.5	19.7	14.84	Inventory		
10-60m	10.2	24.7	18.91			
60-120m	10.9	27.1	20.61			

NR - no results - oxygen electrode inaccurate

6.1.18. LOCH ETIVE - DEEP STATION
CTD Results 22nd June 1992

Depth (m)	Temp. (oC)	Salinity (ppt)	sigma-T (kg/m3)	Dissolved Oxygen (ppm)	(%)	Current Velocity (cm/s)
0.5	14.0	21.7	15.94	5.7	1.11	0.0
1.0	13.9	22.2	16.34	5.9	1.15	0.0
2.0	13.1	23.2	17.26	5.8	1.11	0.0
3.0	11.8	24.1	18.17	5.9	1.12	0.0
4.0	11.3	24.5	18.57	5.8	1.08	0.0
5.0	11.3	24.8	18.80	5.8	1.08	0.0
6.0	11.4	24.9	18.86	5.8	1.10	0.0
7.0	11.5	25.0	18.92	5.7	1.08	0.0
8.0	11.6	25.0	18.90	5.7	1.08	0.0
9.0	11.7	25.1	18.97	5.7	1.08	0.0
10.0	11.7	25.2	19.04	5.6	1.06	0.0
15.0	11.8	25.5	19.26	5.4	1.04	0.0
20.0	12.2	26.0	19.58	5.5	1.06	0.0
25.0	12.2	26.1	19.65	5.5	1.06	0.0
30.0	12.2	26.2	19.73	5.6	1.08	0.1
35.0	12.2	26.4	19.89	5.5	1.06	0.1
40.0	12.1	26.5	19.98	5.4	1.04	0.1
45.0	12.1	26.6	20.06	5.4	1.04	0.0
50.0	12.1	26.6	20.06	5.4	1.04	0.0
55.0	12.1	26.7	20.14	5.3	1.02	0.0
60.0	12.1	26.8	20.21	5.3	1.02	0.0
65.0	12.0	26.8	20.23	5.1	0.98	0.0
70.0	11.7	26.8	20.28	4.6	0.88	0.0
74.5	11.3	26.9	20.43	3.7	0.71	0.0
79.5	11.1	26.9	20.46	2.9	0.55	0.0
84.5	11.0	27.0	20.56	2.6	0.49	0.0
89.5	10.9	27.0	20.57	2.5	0.47	0.0
94.5	10.9	27.0	20.57	2.3	0.44	0.0
99.5	10.9	27.0	20.57	2.3	0.44	0.0
104.5	10.8	27.1	20.67	2.2	0.42	0.0
0-10m	12.1	24.2	18.16	Inventory		
10-60m	12.1	26.3	19.86			
60-120m	11.2	26.9	20.48			

B6.2. LOCH ETIVE DEEP STATION
Nutrient and oxygen results

B6.2.1. Dissolved Oxygen

Depth (m)	Date 21/11/90	20/12/90	6/2/91	22/3/91	18/4/91	22/5/91	18/6/91	17/7/91	12/9/91	14/10/91	13/11/91	12/12/91	24/2/92	23/4/92	28/5/92	20/6/92
0	ND	ND	7.63	8.76	8.70	ND	7.56	6.83	6.25	7.20	7.87	7.55	8.35	9.19	7.76	7.32
5	NS	ND	7.49	8.83	ND	ND	7.28	6.43	5.73	6.52	7.80	ND	8.35	8.83	7.82	7.38
10	ND	ND	6.93	8.62	9.40	ND	ND	6.63	5.73	5.92	6.48	7.07	7.55	7.86	7.55	7.38
30	ND	ND	5.74	6.79	6.60	ND	6.24	5.49	5.66	5.18	4.78	5.46	5.52	6.93	6.07	6.78
50	ND	ND	5.04	ND	7.01	ND	6.39	5.22	5.52	5.04	4.98	6.06	3.64	3.96	3.51	ND
70	ND	ND	4.34	6.40	6.27	ND	5.59	4.95	4.16	4.71	4.30	4.99	3.17	3.37	3.24	2.89
90	ND	ND	3.50	5.39	5.06	ND	4.04	4.08	3.83	3.77	3.81	4.72	3.10	3.06	3.10	2.82
110	ND	ND	3.57	5.39	5.82	ND	4.04	4.28	4.50	4.10	3.86	4.42	2.76	2.80	3.07	6.44

B6.2.2. Dissolved Phosphate

Depth (m)	Date 21/11/90	20/12/90	6/2/91	22/3/91	18/4/91	22/5/91	18/6/91	17/7/91	12/9/91	14/10/91	13/11/91	12/12/91	24/2/92	23/4/92	28/5/92	20/6/92
0	0.05	0.38	0.38	0.23	ND	0.06	0.16	0.07	0.25	0.22	0.16	ND	0.14	ND	ND	ND
5	NS	0.46	0.35	0.27	ND	0.09	0.16	0.12	0.63	0.20	0.12	ND	0.25	ND	ND	ND
10	0.39	0.50	0.35	0.48	ND	0.12	0.29	0.21	0.34	0.33	0.20	ND	0.37	ND	ND	ND
30	0.54	0.52	0.37	0.72	ND	0.21	0.43	0.44	0.39	0.61	0.55	ND	0.35	ND	ND	ND
50	0.98	0.66	0.91	0.83	ND	0.27	0.34	1.34	0.49	0.58	0.60	ND	0.52	ND	ND	ND
70	0.76	0.97	1.26	1.09	ND	0.85	0.63	0.50	1.04	0.70	0.71	ND	0.63	ND	ND	ND
90	1.25	1.14	1.46	1.43	ND	1.01	1.00	0.81	1.33	1.26	1.27	ND	0.74	ND	ND	ND
110	1.36	1.24	1.50	1.51	ND	1.05	1.05	0.93	0.67	1.35	1.35	ND	0.83	ND	ND	ND

B6.2.3. Dissolved Silicate

Depth (m)	Date 21/11/90	20/12/90	6/2/91	22/3/91	18/4/91	22/5/91	18/6/91	17/7/91	12/9/91	14/10/91	13/11/91	12/12/91	24/2/92	23/4/92	28/5/92	20/6/92
0	6.6	12.3	11.3	7.4	ND	4.1	6.8	8.5	1.4	13.4	17.9	ND	14.9	ND	ND	ND
5	NS	12.2	ND	12.7	ND	3.4	3.1	7.8	5.7	13.0	18.6	ND	14.9	ND	ND	ND
10	12.4	12.0	12.2	15.1	ND	5.6	6.5	5.8	7.8	11.8	18.4	ND	14.7	ND	ND	ND
30	16.9	11.0	12.3	12.4	ND	4.4	8.1	10.3	8.6	10.0	14.5	ND	14.6	ND	ND	ND
50	20.2	15.3	14.4	13.1	ND	6.2	7.5	7.5	16.2	10.4	13.6	ND	21.0	ND	ND	ND
70	12.8	22.6	19.1	19.1	ND	21.3	12.3	17.1	26.1	17.0	26.7	ND	26.7	ND	ND	ND
90	24.1	25.0	22.3	24.7	ND	24.7	24.1	21.4	26.8	22.9	31.8	ND	33.5	ND	ND	ND
110	25.9	29.3	26.0	25.4	ND	26.2	26.9	24.2	20.6	24.8	31.8	ND	37.9	ND	ND	ND

NS no sample
ND not determined

B6.3. Monthly Rainfall for the Etive catchment in millimetres and percentage of monthly mean, October 90 - June 92. (Courtesy Meteorological Office)

Name	Black Mount		Ben Cruachan		Inverawe Power Station		Cruachan Power Station		Glenlochy Crossing		Airidh Castulaich		Dunstaffnage Marine Lab.		Dalness Forest Glen Etive	
Height AMSL	175m		427m		54m		43m		200m		111m		3m		72m	
Grid Ref.	E 2282 N 7427		E 2085 N 7295		E 2018 N 7323		E 2079 N 7268		E 2254 N 7293		E 2256 N 7342		E 1881 N 7340		E 2164 N 7509	
	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)
Oct 90	336	NA	477	131	274	NA	328	NA	398	137	309	114	330	NA	381	NA
Nov 90	102	NA	178	63	88	NA	104	NA	147	62	137	62	64	NA	148	NA
Dec 90	330	NA	423	116	275	NA	293	NA	397	131	406	144	250	NA	450	NA
Jan 91	291	NA	338	117	199	NA	245	NA	313	129	300	132	178	NA	NA	NA
Feb 91	109	NA	124	59	66	NA	83	NA	115	56	109	57	65	NA	NA	NA
Mar 91	190	NA	258	130	156	NA	170	NA	240	134	250	149	150	NA	NA	NA
Apr 91	212	NA	301	151	206	NA	244	NA	272	158	239	148	149	NA	NA	NA
May 91	38	NA	103	60	49	NA	61	NA	55	39	34	25	35	NA	NA	NA
Jun 91	144	NA	228	113	137	NA	152	NA	175	117	150	106	98	NA	NA	NA
Jul 91	119	NA	233	102	90	NA	127	NA	118	74	121	81	101	NA	NA	NA
Aug 91	109	NA	225	87	84	NA	119	NA	117	61	95	54	82	NA	NA	NA
Sep 91	274	NA	297	91	202	NA	225	NA	293	119	287	125	159	NA	NA	NA
Oct 91	301	NA	366	101	221	NA	245	NA	336	116	334	123	175	NA	NA	NA
Nov 91	384	NA	547	196	335	NA	372	NA	448	189	410	184	271	NA	NA	NA
Dec 91	255	NA	349	96	235	NA	219	NA	285	94	236	83	196	NA	NA	NA
Jan 92	333	NA	372	128	219	NA	292	NA	302	125	340	150	224	NA	446	NA
Feb 92	391	NA	437	206	257	NA	312	NA	413	202	400	210	262	NA	534	NA
Mar 92	368	NA	547	275	275	NA	383	NA	431	242	362	217	256	NA	636	NA
Apr 92	142	NA	281	141	146	NA	187	NA	207	120	162	101	127	NA	286	NA
May 92	119	NA	227	133	98	NA	115	NA	176	125	140	106	89	NA	202	NA
Jun 92	38	NA	80	40	45	NA	45	NA	68	45	33	24	37	NA	92	NA
1990	3325	145	4701	152	2411	132	2983	142	3828	153	3448	147	2266	152	4749	158
1991	2424	105	3369	109	1978	108	2259	108	2764	110	2566	109	1657	111	NA	NA
1992	2852	124	NA	NA	2222	121	2748	131	3254	130	2925	125	2107	141	4325	144
30 year mean (1941-1970)	2300	-	3095	-	1830	-	2100	-	2509	-	2347	-	1490	-	3000	-

B6.4. Weekly rainfall, run-off to Awe, input to Etive from Loch Awe, and total input to Etive, November 1990 - June 1992

	<---------- Rainfall (mm) ---------->					Run-off	<-- freshwater input -->	
Name	Black Mount	D'staffnage Marine Lab.	Cruachan Power S.	Inverawe Power S.	Loch Nant	to Awe from catchment	from Awe	total
Height AMSL	175m	3m	43m	54m	211m??	(Mm3)	(Mm3)	(Mm3)
Week Ending								
02-Nov-90	48.8	61.1	58.7	NA	NA	43.0	40.9	66.2
09-Nov-90	0.5	1.5	2.0	NA	NA	6.4	18.5	22.3
16-Nov-90	47.7	31.0	54.1	NA	NA	23.0	21.4	35.0
23-Nov-90	51.7	31.2	47.3	NA	NA	101.1	110.4	169.8
30-Nov-90	1.3	0.3	0.2	NA	NA	15.5	15.6	24.7
07-Dec-90	38.5	26.3	32.2	NA	NA	20.7	17.6	29.8
14-Dec-90	17.1	11.8	18.4	NA	NA	19.3	23.9	35.3
21-Dec-90	61.1	41.9	55.1	NA	NA	22.1	18.3	31.4
28-Dec-90	162.6	105.2	139.6	NA	NA	118.7	106.1	175.8
04-Jan-91	189.5	133.1	137.2	NA	NA	108.5	109.8	173.6
11-Jan-91	62.9	54.1	62.5	NA	NA	61.7	81.1	117.3
18-Jan-91	17.9	18.0	20.9	NA	NA	15.1	28.2	37.1
25-Jan-91	65.2	30.0	50.5	NA	NA	77.1	68.3	113.6
01-Feb-91	6.1	7.6	12.8	NA	NA	9.4	24.9	30.5
08-Feb-91	2.4	0.0	0.0	NA	NA	4.4	5.1	7.7
15-Feb-91	10.8	16.5	17.3	NA	NA	5.3	5.4	8.5
22-Feb-91	52.1	24.3	41.3	NA	NA	16.3	14.0	23.6
01-Mar-91	43.4	23.8	24.0	NA	NA	52.8	54.3	85.3
08-Mar-91	39.9	28.3	25.7	NA	NA	33.1	31.1	50.5
15-Mar-91	18.8	24.4	31.4	NA	NA	10.9	17.5	23.9
22-Mar-91	85.2	71.4	87.9	NA	NA	91.7	70.2	124.1
29-Mar-91	1.6	2.1	2.6	NA	NA	4.7	21.5	24.3
05-Apr-91	117.3	77.8	121.9	88.2	120.6	96.5	76.7	133.4
12-Apr-91	126.6	85.7	116.7	115.0	123.7	113.6	114.1	180.8
19-Apr-91	0.7	2.2	5.7	11.2	10.9	17.4	41.4	51.6
26-Apr-91	11.1	6.5	22.1	10.5	18.9	6.4	23.0	26.8
03-May-91	0.4	0.2	0.4	0.0	0.0	3.1	6.5	8.2
10-May-91	5.7	4.3	7.3	1.4	0.8	3.1	6.4	8.3
17-May-91	18.2	14.7	16.4	20.3	20.4	11.4	6.4	13.1
24-May-91	13.9	15.0	35.2	26.3	13.1	16.5	6.4	16.1
31-May-91	0.0	1.2	1.3	0.3	0.8	6.9	6.4	10.5
07-Jun-91	15.2	19.6	17.3	17.3	21.1	3.5	9.0	11.0
14-Jun-91	65.2	49.6	62.4	68.9	90.4	33.9	23.6	43.5
21-Jun-91	15.7	4.0	23.2	6.7	2.6	5.6	17.6	20.9
28-Jun-91	34.9	12.1	31.3	31.3	0.3	18.4	16.1	26.9
05-Jul-91	27.2	18.4	32.1	25.2	7.4	20.4	14.2	26.2
12-Jul-91	58.5	45.1	51.9	30.3	40.7	15.9	19.4	28.7
19-Jul-91	26.7	23.8	34.5	60.4	29.5	43.0	38.2	63.5
26-Jul-91	9.4	10.0	12.1	11.5	9.2	9.7	16.0	21.7
02-Aug-91	10.9	22.5	18.8	7.3	24.9	8.3	10.7	15.5
09-Aug-91	51.3	24.8	49.1	33.3	27.7	16.1	13.8	23.3
16-Aug-91	46.9	27.9	31.5	15.2	27.0	23.0	25.7	39.2
23-Aug-91	9.7	24.7	31.2	31.5	27.2	24.2	24.5	38.7
30-Aug-91	0.0	0.4	2.5	3.1	2.0	10.1	11.1	17.0
06-Sep-91	0.0	0.0	0.0	0.0	0.0	1.7	9.0	10.0
13-Sep-91	34.6	38.5	35.9	3.7	0.0	0.0	9.0	9.0
20-Sep-91	83.8	43.1	65.5	96.6	80.1	51.2	31.6	61.7
27-Sep-91	139.5	70.9	111.2	99.9	134.3	110.2	97.9	162.6
04-Oct-91	120.6	55.5	90.3	38.7	64.5	39.3	53.4	76.5
11-Oct-91	45.0	33.5	38.7	60.8	40.3	73.3	80.5	123.6
18-Oct-91	78.6	48.2	66.4	50.0	80.7	46.6	35.9	63.2
25-Oct-91	0.7	0.8	4.5	NA	NA	NA	NA	NA
01-Nov-91	102.3	65.5	81.5	65.5	53.4	35.8	21.4	42.4
08-Nov-91	91.7	52.2	104.5	117.0	150.2	96.6	79.3	136.1
15-Nov-91	127.2	87.9	106.4	92.6	134.3	90.4	109.8	162.9
22-Nov-91	46.7	39.0	66.2	34.6	45.4	38.7	44.1	66.8
29-Nov-91	87.3	67.3	68.2	81.0	114.3	79.2	75.4	121.9
06-Dec-91	1.4	2.1	2.1	5.3	8.0	14.0	41.1	49.3
13-Dec-91	24.8	13.7	12.7	0.6	10.0	7.3	10.3	14.6
20-Dec-91	92.7	71.9	67.6	48.2	68.9	59.7	39.9	75.0
27-Dec-91	101.2	76.3	109.6	105.5	118.5	105.7	106.2	168.3
03-Jan-92	229.4	160.9	181.1	112.5	238.4	135.3	109.1	188.6
10-Jan-92	114.8	74.2	111.7	85.7	103.2	133.5	161.5	239.9
17-Jan-92	5.0	1.9	5.3	3.4	6.2	12.1	47.1	54.2
24-Jan-92	16.5	19.5	20.9	6.3	8.0	8.7	16.1	21.2
31-Jan-92	3.2	2.0	1.2	16.4	31.0	9.6	12.7	18.4
07-Feb-92	70.9	56.9	74.9	42.0	47.4	37.0	39.7	61.5
14-Feb-92	75.0	49.0	59.9	63.3	31.7	58.7	53.3	87.8
21-Feb-92	107.3	54.2	53.8	23.3	47.5	32.3	37.2	56.1
28-Feb-92	149.2	75.1	104.7	105.4	168.8	128.8	108.8	184.4
06-Mar-92	125.3	107.0	138.3	71.0	135.1	86.4	89.2	140.0
13-Mar-92	98.8	63.3	88.6	88.7	90.6	102.1	109.1	169.1
20-Mar-92	107.3	77.5	107.3	64.7	145.3	93.9	80.6	135.8
27-Mar-92	24.6	17.4	46.4	42.1	52.0	41.3	62.1	86.4
03-Apr-92	22.1	17.3	20.3	20.7	22.8	22.3	33.3	46.4
10-Apr-92	14.5	13.7	19.9	11.4	31.1	13.6	25.4	33.4
17-Apr-92	38.8	29.3	62.2	22.3	26.3	15.6	19.3	28.5
24-Apr-92	19.8	26.2	41.1	41.4	61.9	34.2	27.9	48.0
01-May-92	71.2	60.5	66.8	66.0	88.9	56.7	56.8	90.1
08-May-92	62.4	38.9	66.1	55.5	75.3	56.2	49.7	82.7
15-May-92	33.7	27.7	34.2	35.2	14.5	38.5	59.2	81.8
22-May-92	8.5	8.1	8.0	8.7	16.1	7.7	13.3	17.8
29-May-92	3.3	8.7	0.0	0.0	1.4	3.4	6.4	8.4
05-Jun-92	8.8	6.2	15.7	22.6	11.1	1.8	9.0	10.0
12-Jun-92	0.0	4.1	2.8	2.4	4.7	1.9	9.0	10.1
19-Jun-92	15.1	9.6	13.0	13.9	14.8	4.8	9.0	11.8
26-Jun-92	16.4	8.7	15.2	6.6	14.4	1.3	9.0	9.7
03-Jul-92	18.3	18.2	9.5	6.7	18.8	1.3	9.0	9.7

NA not availible

B6.5. 210-Pb and 210-Po activities and inventories in the deep basin of Loch Etive

B6.5.1. 21st November 1990

Depth	210-Pb Activity (Bq m-3)						210-Po Activity (Bq m-3)					
(m)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	0.990	0.036	0.712	0.061	1.701	0.098	1.022	0.054	2.732	0.190	3.754	0.198
5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10	0.119	0.008	0.281	0.037	0.400	0.045	0.397	0.055	0.366	0.033	0.763	0.064
30	0.395	0.026	0.475	0.041	0.870	0.067	0.411	0.033	0.305	0.030	0.716	0.045
50	0.091	0.008	0.267	0.029	0.359	0.037	0.232	0.034	0.114	0.012	0.347	0.036
70	0.109	0.013	0.154	0.015	0.263	0.028	0.232	0.022	0.078	0.009	0.310	0.024
90	0.138	0.010	0.052	0.009	0.189	0.019	0.384	0.034	0.102	0.013	0.486	0.037
110	0.101	0.009	0.233	0.020	0.334	0.029	0.271	0.024	0.172	0.015	0.443	0.028
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	5.54	0.30	4.96	0.55	10.51	0.85	7.09	0.75	15.49	1.26	22.59	1.46
10-60	10.92	1.84	17.64	4.15	28.56	5.99	16.83	4.64	12.05	2.68	28.89	5.36
60-120	6.96	1.60	8.77	2.74	15.73	4.34	17.74	3.95	7.03	1.92	24.77	4.39
0-120	23.42	6.80	31.37	12.77	54.80	19.57	41.66	15.40	34.57	12.48	76.24	19.82

B6.5.2. 20th December 1990

Depth	210-Pb Activity (Bq m-3)						210-Po Activity (Bq m-3)					
(m)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	0.368	0.023	0.777	0.046	1.145	0.051	0.376	0.024	0.341	0.032	0.716	0.040
5	0.195	0.019	0.932	0.081	1.127	0.083	0.290	0.023	0.286	0.022	0.576	0.032
10	0.232	0.023	0.715	0.061	0.947	0.065	0.345	0.025	0.297	0.022	0.642	0.033
30	0.194	0.012	0.399	0.069	0.593	0.070	0.458	0.038	0.238	0.022	0.697	0.044
50	0.716	0.050	0.421	0.027	1.136	0.057	0.321	0.025	0.280	0.023	0.601	0.034
70	0.367	0.029	0.214	0.019	0.581	0.035	0.349	0.025	0.141	0.013	0.490	0.028
90	0.132	0.019	0.277	0.059	0.409	0.062	0.155	0.020	0.069	0.009	0.224	0.022
110	0.121	0.015	0.211	0.019	0.331	0.024	0.200	0.023	0.129	0.012	0.330	0.026
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	2.48	0.23	8.39	0.67	10.87	0.71	3.25	0.24	3.02	0.24	6.28	0.34
10-60	20.52	3.39	23.53	6.44	44.05	7.28	19.04	3.36	13.34	2.52	32.38	4.20
60-120	12.40	3.66	14.04	4.90	26.44	6.11	14.08	3.73	6.79	1.80	20.87	4.14
0-120	35.39	12.39	45.96	20.71	81.35	24.14	36.37	11.89	23.16	7.75	59.53	14.19

B6.5.3. 6th February 1991

Depth	210-Pb Activity (Bq m-3)						210-Po Activity (Bq m-3)					
(m)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	0.143	0.015	0.334	0.045	0.478	0.060	0.406	0.024	0.514	0.036	0.921	0.059
5	0.393	0.034	0.152	0.014	0.544	0.048	0.376	0.026	0.376	0.028	0.751	0.053
10	0.247	0.020	0.149	0.018	0.397	0.038	0.643	0.049	0.391	0.028	1.034	0.077
30	0.103	0.010	0.145	0.014	0.248	0.024	0.244	0.020	0.263	0.021	0.507	0.041
50	ND	ND	0.080	0.008	ND	ND	ND	ND	0.099	0.012	0.099	0.012
70	0.046	0.004	0.104	0.010	0.150	0.014	0.286	0.034	0.098	0.013	0.385	0.047
90	0.060	0.008	0.089	0.011	0.149	0.019	0.108	0.015	0.078	0.011	0.185	0.026
110	0.266	0.027	0.086	0.009	0.352	0.037	0.707	0.041	0.119	0.016	0.827	0.057
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	2.94	0.26	1.97	0.22	4.91	0.49	4.50	0.30	4.14	0.30	8.64	0.60
10-60	6.02	1.22	5.98	1.43	12.00	2.64	16.61	3.29	11.16	2.44	27.76	5.73
60-120	7.45	1.94	5.58	1.50	13.03	3.44	22.03	5.94	5.91	1.94	27.93	7.88
0-120	16.42	5.61	13.52	5.09	29.94	10.70	43.14	14.72	21.21	8.50	64.34	23.21

B6.5.4. 22nd March 1991

Depth	210-Pb Activity (Bq m-3)						210-Po Activity (Bq m-3)					
(m)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	0.346	0.026	1.169	0.058	1.515	0.084	0.754	0.028	1.789	0.121	2.542	0.148
5	1.100	0.067	0.986	0.045	2.087	0.112	2.245	0.066	1.668	0.114	3.913	0.180
10	0.600	0.085	0.544	0.041	1.144	0.126	0.571	0.029	0.600	0.050	1.171	0.079
30	0.160	0.018	0.156	0.015	0.316	0.033	0.134	0.019	0.203	0.025	0.337	0.044
50	0.247	0.019	0.126	0.012	0.373	0.031	0.417	0.031	0.185	0.017	0.602	0.048
70	0.113	0.012	0.166	0.015	0.279	0.027	0.533	0.027	0.196	0.017	0.729	0.045
90	0.527	0.041	0.134	0.021	0.661	0.062	0.987	0.037	0.160	0.015	1.147	0.052
110	0.429	0.035	0.149	0.013	0.578	0.048	0.350	0.023	0.151	0.020	0.501	0.043
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	7.87	0.72	9.21	0.51	17.08	1.23	14.54	0.55	14.31	1.03	28.85	1.58
10-60	14.14	3.37	11.09	2.25	25.23	5.62	16.73	3.85	13.76	3.21	30.49	7.06
60-120	21.38	4.66	8.98	2.55	30.35	7.21	37.40	4.88	10.15	2.65	47.55	7.52
0-120	43.39	14.56	29.28	10.34	72.67	24.90	68.67	18.33	38.23	13.66	106.90	31.99

B6.5.5. 18th April 1991

Depth	210-Pb Activity (Bq m-3)						210-Po Activity (Bq m-3)					
(m)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	1.021	0.061	0.616	0.039	1.636	0.100	1.112	0.062	1.045	0.060	2.157	0.123
5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10	0.224	0.016	0.684	0.044	0.908	0.060	0.410	0.033	0.852	0.048	1.262	0.081
30	0.100	0.010	0.200	0.018	0.299	0.028	0.173	0.026	0.186	0.014	0.360	0.040
50	0.127	0.012	0.124	0.010	0.251	0.022	0.198	0.021	0.262	0.018	0.460	0.038
70	0.178	0.017	0.218	0.016	0.395	0.033	0.575	0.039	0.170	0.016	0.745	0.055
90	0.105	0.013	0.288	0.022	0.393	0.035	0.154	0.018	0.131	0.013	0.285	0.031
110	0.075	0.009	0.180	0.012	0.256	0.021	0.135	0.019	0.164	0.016	0.299	0.034
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	6.22	0.41	6.50	0.42	12.72	0.83	7.61	0.52	9.49	0.54	17.10	1.07
10-60	6.77	1.42	13.32	2.42	20.09	3.84	11.53	3.11	17.50	2.72	29.03	5.83
60-120	7.17	1.95	13.72	2.41	20.89	4.36	17.30	4.71	9.31	2.19	26.60	6.90
0-120	20.16	7.04	33.54	8.75	53.70	15.79	36.44	14.18	36.29	10.44	72.73	24.61

B6.5.6. 22nd May 1991

Depth	210-Pb Activity (Bq m-3)						210-Po Activity (Bq m-3)					
(m)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	0.473	0.037	0.784	0.057	1.257	0.095	0.394	0.028	0.703	0.055	1.097	0.082
5	0.184	0.014	0.508	0.033	0.692	0.047	0.360	0.026	0.560	0.043	0.920	0.069
10	0.153	0.015	0.308	0.022	0.461	0.037	0.283	0.025	0.264	0.024	0.547	0.048
30	0.119	0.016	0.261	0.030	0.380	0.046	0.179	0.016	0.356	0.031	0.535	0.047
50	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
70	0.214	0.019	0.110	0.009	0.325	0.028	0.278	0.020	0.166	0.015	0.444	0.035
90	0.063	0.007	0.126	0.010	0.188	0.017	3.408	0.096	0.127	0.013	3.535	0.109
110	0.082	0.009	0.138	0.014	0.220	0.023	0.161	0.015	0.130	0.013	0.292	0.027
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	2.48	0.20	5.27	0.36	7.75	0.57	3.49	0.26	5.22	0.42	8.71	0.69
10-60	7.24	1.93	12.02	2.73	19.26	4.67	10.98	2.13	14.97	2.95	25.95	5.07
60-120	7.18	1.82	7.49	1.59	14.67	3.41	76.93	13.05	8.47	1.98	85.41	15.03
0-120	16.90	6.38	24.79	7.90	41.69	14.28	91.40	24.53	28.66	9.07	120.06	33.60

B6.5.7. 18th June 1991

Depth	210-Pb Activity (Bq m-3)						210-Po Activity (Bq m-3)					
(m)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	0.283	0.031	0.734	0.045	1.017	0.076	0.733	0.038	1.278	0.079	2.010	0.117
5	0.143	0.014	0.308	0.022	0.451	0.037	0.438	0.034	0.653	0.048	1.091	0.082
10	0.155	0.017	0.154	0.014	0.309	0.031	0.301	0.028	0.139	0.014	0.440	0.042
30	0.160	0.015	0.125	0.014	0.285	0.029	0.364	0.033	0.132	0.014	0.496	0.047
50	0.140	0.014	0.121	0.012	0.261	0.026	0.202	0.022	0.169	0.015	0.371	0.037
70	0.208	0.019	0.187	0.024	0.396	0.043	0.179	0.018	0.171	0.016	0.350	0.034
90	0.074	0.009	0.096	0.010	0.170	0.019	0.167	0.017	0.145	0.015	0.313	0.032
110	0.072	0.009	0.119	0.016	0.191	0.025	0.163	0.018	0.116	0.013	0.279	0.031
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	1.81	0.19	3.76	0.28	5.57	0.47	4.78	0.36	6.80	0.54	11.58	0.90
10-60	7.56	1.72	6.46	1.47	14.02	3.19	14.33	3.17	7.41	1.66	21.74	4.84
60-120	7.08	1.95	8.05	2.41	15.14	4.36	10.18	2.60	8.65	2.19	18.83	4.79
0-120	16.45	6.13	18.28	7.01	34.72	13.14	29.29	10.14	22.86	7.95	52.15	18.09

B6.5.8. 17th July 1991

Depth	210-Pb Activity (Bq m-3)						210-Po Activity (Bq m-3)					
(m)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	0.338	0.034	0.889	0.058	1.227	0.092	0.478	0.023	1.054	0.066	1.532	0.089
5	0.126	0.010	0.432	0.043	0.558	0.053	0.443	0.026	0.591	0.043	1.034	0.069
10	0.094	0.008	0.223	0.024	0.316	0.032	0.276	0.020	0.349	0.029	0.626	0.049
30	0.068	0.006	0.101	0.011	0.169	0.018	0.179	0.018	0.194	0.019	0.373	0.037
50	0.111	0.011	0.112	0.013	0.223	0.024	0.149	0.013	0.189	0.017	0.337	0.030
70	0.048	0.005	ND	ND	ND	ND	0.141	0.016	0.148	0.016	0.289	0.032
90	0.047	0.005	0.078	0.008	0.125	0.013	0.100	0.009	0.117	0.012	0.217	0.021
110	0.073	0.009	0.113	0.012	0.186	0.020	0.105	0.010	0.128	0.013	0.233	0.023
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	1.71	0.15	4.94	0.47	6.65	0.62	4.10	0.24	6.46	0.48	10.57	0.72
10-60	4.51	0.97	6.48	1.63	10.99	2.60	9.31	1.88	11.14	2.31	20.45	4.19
60-120	3.37	0.91	5.72	1.45	9.09	2.36	6.93	1.68	7.86	1.99	14.79	3.67
0-120	9.59	3.41	17.14	6.34	26.73	9.75	20.35	6.52	25.46	8.55	45.81	15.08

NS no sample ND not done

B6.5. 210-Pb and 210-Po activities and inventories in the deep basin of Loch Etive (continued)

B6.5.9. 13th September 1991

Depth (m)	210-Pb Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	210-Po Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	0.247	0.020	0.051	0.007	0.298	0.027	0.191	0.014	0.229	0.017	0.420	0.031
5	0.147	0.015	0.673	0.079	0.819	0.094	0.275	0.019	0.177	0.015	0.453	0.034
10	0.184	0.016	0.206	0.020	0.391	0.036	0.319	0.015	0.179	0.014	0.499	0.029
30	0.236	0.025	0.135	0.010	0.371	0.035	0.182	0.016	0.254	0.019	0.436	0.035
50	0.484	0.039	0.241	0.019	0.725	0.059	0.219	0.011	0.259	0.019	0.477	0.030
70	0.290	0.023	0.127	0.015	0.417	0.038	0.221	0.020	0.126	0.013	0.347	0.033
90	0.144	0.010	0.132	0.016	0.276	0.026	0.172	0.020	0.109	0.010	0.281	0.030
110	0.195	0.014	0.121	0.013	0.316	0.027	0.166	0.021	0.109	0.010	0.275	0.031
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	1.81	0.17	4.01	0.47	5.82	0.65	2.65	0.17	1.91	0.15	4.56	0.33
10-60	15.96	3.27	9.35	1.79	25.30	5.06	11.29	1.75	11.52	1.98	22.81	3.73
60-120	12.21	2.19	7.57	2.10	19.78	4.29	10.97	3.07	6.81	1.57	17.79	4.64
0-120	29.98	8.65	20.92	7.48	50.90	16.13	24.92	8.14	20.24	6.03	45.16	14.17

B6.5.10. 14th October 1991

Depth (m)	210-Pb Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	210-Po Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	ND	ND	0.4885	0.0339	ND	ND	0.312	0.018	0.864	0.062	1.176	0.080
5	ND	ND	0.4293	0.0254	ND	ND	0.371	0.024	0.522	0.035	0.893	0.059
10	ND	ND	ND	ND	ND	ND	0.260	0.020	0.336	0.023	0.596	0.043
30	ND	ND	ND	ND	ND	ND	0.176	0.016	0.051	0.007	0.228	0.023
50	ND	ND	ND	ND	ND	ND	0.153	0.013	0.091	0.009	0.244	0.021
70	ND	ND	ND	ND	ND	ND	0.165	0.016	0.090	0.012	0.255	0.028
90	ND	ND	ND	ND	ND	ND	0.187	0.015	0.110	0.011	0.298	0.026
110	ND	ND	ND	ND	ND	ND	0.132	0.014	0.143	0.013	0.275	0.026
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	ND	ND	4.44	0.27	ND	ND	3.29	0.22	5.61	0.39	8.90	0.60
10-60	ND	ND	ND	ND	ND	ND	9.18	1.75	6.21	1.51	15.40	3.26
60-120	ND	ND	ND	ND	ND	ND	9.68	2.25	6.87	1.79	16.55	4.04
0-120	ND	ND	ND	ND	ND	ND	22.15	6.80	18.69	6.80	40.84	13.60

B6.5.11. 13th November 1991

Depth (m)	210-Pb Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	210-Po Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	ND	ND	ND	ND	ND	ND	0.930	0.055	1.685	0.102	2.615	0.157
5	ND	ND	ND	ND	ND	ND	1.491	0.071	1.840	0.176	3.331	0.247
10	ND	ND	ND	ND	ND	ND	0.439	0.042	0.673	0.049	1.113	0.091
30	ND	ND	ND	ND	ND	ND	0.233	0.028	0.217	0.025	0.450	0.053
50	ND	ND	ND	ND	ND	ND	0.230	0.019	0.079	0.010	0.308	0.029
70	ND	ND	ND	ND	ND	ND	0.149	0.011	0.102	0.010	0.251	0.021
90	ND	ND	ND	ND	ND	ND	0.191	0.016	0.087	0.008	0.277	0.024
110	ND	ND	ND	ND	ND	ND	0.167	0.015	0.129	0.019	0.296	0.034
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	ND	ND	ND	ND	ND	ND	10.88	0.71	15.10	1.18	25.98	1.89
10-60	ND	ND	ND	ND	ND	ND	13.65	3.09	12.65	3.24	26.30	6.33
60-120	ND	ND	ND	ND	ND	ND	10.14	2.06	6.35	1.80	16.50	3.86
0-120	ND	ND	ND	ND	ND	ND	34.67	10.79	34.10	13.29	68.77	24.07

B6.5.12. 12th December 1991

Depth (m)	210-Pb Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	210-Po Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	ND	ND	ND	ND	ND	ND	ND	ND	0.370	0.027	ND	ND
5	ND	ND	ND	ND	ND	ND	ND	ND	0.286	0.025	ND	ND
10	ND	ND	ND	ND	ND	ND	ND	ND	0.351	0.027	ND	ND
30	ND	ND	ND	ND	ND	ND	ND	ND	0.141	0.016	ND	ND
50	ND	ND	ND	ND	ND	ND	0.025	0.001	0.093	0.009	ND	ND
70	ND	ND	ND	ND	ND	ND	ND	ND	0.096	0.010	ND	ND
90	ND	ND	ND	ND	ND	ND	ND	ND	0.067	0.008	ND	ND
110	ND	ND	ND	ND	ND	ND	0.031	0.002	0.081	0.009	ND	ND
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	ND	ND	ND	ND	ND	ND	ND	ND	3.23	0.38	ND	ND
10-60	ND	ND	ND	ND	ND	ND	ND	ND	8.20	1.27	ND	ND
60-120	ND	ND	ND	ND	ND	ND	ND	ND	4.87	0.94	ND	ND
0-120	ND	ND	ND	ND	ND	ND	ND	ND	16.30	4.48	ND	ND

B6.5.13. 24th February 1992

Depth (m)	210-Pb Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	210-Po Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	ND	ND	ND	ND	ND	ND	1.453	0.117	2.010	0.144	3.463	0.261
5	ND	ND	ND	ND	ND	ND	0.720	0.031	1.688	0.112	2.409	0.144
10	ND	ND	ND	ND	ND	ND	0.410	0.022	0.770	0.059	1.179	0.081
30	ND	ND	ND	ND	ND	ND	0.338	0.025	0.256	0.023	0.594	0.048
50	ND	ND	ND	ND	ND	ND	0.244	0.018	0.095	0.009	0.339	0.027
70	ND	ND	ND	ND	ND	ND	0.137	0.011	0.121	0.011	0.258	0.022
90	ND	ND	ND	ND	ND	ND	0.207	0.016	0.089	0.008	0.295	0.024
110	ND	ND	ND	ND	ND	ND	0.303	0.019	0.177	0.015	0.480	0.034
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	ND	ND	ND	ND	ND	ND	8.26	0.78	15.39	1.62	23.65	2.40
10-60	ND	ND	ND	ND	ND	ND	15.72	1.70	14.72	1.99	30.45	3.69
60-120	ND	ND	ND	ND	ND	ND	12.93	1.66	7.73	1.18	20.66	2.84
0-120	ND	ND	ND	ND	ND	ND	36.91	7.12	37.85	8.69	74.75	15.81

B6.5.14. 23rd April 1992

Depth (m)	210-Pb Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	210-Po Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	ND	ND	ND	ND	ND	ND	1.214	0.047	1.177	0.078	0.239	0.018
5	ND	ND	ND	ND	ND	ND	0.308	0.025	0.766	0.063	0.107	0.012
10	ND	ND	ND	ND	ND	ND	0.602	0.039	0.394	0.029	0.100	0.010
30	ND	ND	ND	ND	ND	ND	0.217	0.015	0.351	0.034	0.057	0.007
50	ND	ND	ND	ND	ND	ND	NS	NS	NS	NS	0.068	0.003
70	ND	ND	ND	ND	ND	ND	0.161	0.012	0.090	0.010	0.025	0.003
90	ND	ND	ND	ND	ND	ND	NS	NS	NS	NS	0.045	0.003
110	ND	ND	ND	ND	ND	ND	1.198	0.052	0.137	0.012	0.134	0.013
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	ND	ND	ND	ND	ND	ND	6.08	0.57	7.76	0.87	13.84	2.02
10-60	ND	ND	ND	ND	ND	ND	14.14	1.08	15.38	1.60	34.87	4.83
60-120	ND	ND	ND	ND	ND	ND	40.75	3.44	6.83	0.98	40.81	7.31
0-120	ND	ND	ND	ND	ND	ND	60.98	9.00	29.97	6.27	89.51	24.14

B6.1.15. 28th May 1992

Depth (m)	210-Pb Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	210-Po Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	0.0657	0.0034
5	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	0.0874	0.0038
10	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	0.1163	0.0086
30	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	0.0586	0.0039
50	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	0.0355	0.0019
70	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	0.0280	0.0019
90	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	0.0587	0.0028
110	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	0.0322	0.0023
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	8.9198	0.6873
10-60	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	30.4569	2.8402
60-120	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	23.7688	2.5693
0-120	NS	NS	NS	NS	ND	ND	NS	NS	NS	NS	63.1455	10.2442

B6.5.16. 20th June 1992

Depth (m)	210-Pb Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)	210-Po Activity (Bq m-3) Dissolved	(+/-)	Particulate	(+/-)	Total	(+/-)
0	ND	ND	ND	ND	ND	ND	3.952	0.107	0.236	0.018	4.188	0.125
5	ND	ND	ND	ND	ND	ND	0.615	0.056	0.179	0.016	0.794	0.071
10	ND	ND	ND	ND	ND	ND	0.363	0.034	0.216	0.022	0.579	0.056
30	ND	ND	ND	ND	ND	ND	0.205	0.017	0.231	0.024	0.436	0.040
50	ND	ND	ND	ND	ND	ND	0.114	0.011	0.177	0.015	0.291	0.026
70	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
90	ND	ND	ND	ND	ND	ND	0.098	0.010	0.156	0.012	0.254	0.022
110	ND	ND	ND	ND	ND	ND	0.360	0.026	0.202	0.025	0.562	0.051
	210-Pb Inventory (Bq m-2)						210-Po Inventory (Bq m-2)					
0-10	ND	ND	ND	ND	ND	ND	13.87	0.73	2.02	0.18	15.89	0.91
10-60	ND	ND	ND	ND	ND	ND	10.47	1.10	10.60	1.30	21.07	2.40
60-120	ND	ND	ND	ND	ND	ND	11.36	1.49	10.59	1.62	21.95	3.11
0-120	ND	ND	ND	ND	ND	ND	35.70	6.29	23.21	4.97	58.91	11.27

NS no sample ND not done

B7.1. Pore Water Results - Core F
Loch Etive Deep Station 18/1/93

Sample	Depth Interval (cm)	phosphate conc. (umols)	error (umols)	Fe conc. (ppm)	error (%)	Mn conc. (ppm)	error (%)	Pb-210 activity per 100l (Bq/100l)	total error (+/-)
F1	0-1	20	1	0.14	62.0	27.0	0.3	0.8521	0.1007
F2	1-2	8	1	0.17	79.3	35.9	0.6	0.5280	0.0904
F3	2-3	35	1	0.25	20.3	44.3	0.8		
F4	3-4	11	1	0.11	43.2	63.7	1.1		
F5	4-5	45	1	0.49	4.3	46.9	0.0	0.4134	0.0680
F6	5-6	13	1	0.38	2.3	43.4	0.6		
F7	6-7	16	1	0.33	8.3	43.4	0.9		
F8	7-8	20	1	2.19	0.8	47.0	0.5	BDL	BDL
F9	8-9	20	1	1.45	0.2	37.3	0.1		
F10	9-10	31	1	0.93	2.1	38.7	0.4		
F11	10-11	34	1	4.29	1.2	33.3	0.3	0.2685	0.5330
F12	11-12	35	1	4.67	1.5	35.8	0.8		
F13	12-13	42	1	5.80	1.6	33.7	0.4		
F14	13-14	48	1	5.11	2.7	34.6	0.6	0.3128	0.6100
F15	14-15	9	1	2.34	0.0	34.6	0.1		
F16	15-16	45	1	5.97	2.4	31.2	0.6		
F17	16-17	26	1	5.58	1.8	31.1	0.3		
F18	17-18	50	1	6.09	0.3	31.8	0.9	0.2901	0.0508
F19	18-19	15	1	2.65	2.4	28.0	0.5		
F20	19-20	37	1	5.40	2.6	30.4	0.4		
F21	20-22	11	1	0.81	0.0	27.1	1.1		
F22	22-24	47	1	4.23	2.1	20.8	0.4	0.1803	0.0417
F23	24-26	54	1	4.14	1.3	19.3	0.4		
F24	26-28	57	1	4.03	0.3	16.0	0.6	BDL	BDL
F25	28-30	76	1	2.92	1.3	14.0	0.2		
F26	30-32	57	1	1.66	4.6	14.7	0.9		
F27	32-34	95	1	0.75	3.2	13.8	1.1	0.2801	0.0437
F28	34-36	93	1	0.39	1.4	12.0	0.3		
F29	36-38	94	1	0.62	4.6	11.7	0.0	0.1970	0.5800
F30	38-40	112	1	1.00	1.7	12.7	0.1		
F31	40-42	98	1	0.43	6.3	11.9	1.0		
F32	42-44	114	1	0.38	5.7	11.3	0.6		
F33	44-46	95	1	1.08	2.2	12.2	0.2		
F34	46-48	119	1	0.50	0.3	11.6	0.4		
F35	48-50	126	1	0.31	19.5	11.1	0.4		
F36	50-52	119	1	0.26	5.3	10.2	0.7		
F37	52-54	140	1	0.52	15.5	10.3	0.2		
F38	54-56	128	1	0.28	42.6	11.0	1.1		
F39	56-58	119	1	0.42	11.8	10.5	1.1		
F40	58-60	115	1	0.44	8.9	10.4	1.0		

BDL - below detection level

B8.1.1. Core A (Deep Station, 22.5.91) 210-Pb results and accumulation rate calculation

	Depth (cm)	210-Pb (Bq/kg)	excess 210-Pb (Bq/kg)	(+/-)	ln excess 210-Pb	(+/-)	Depth (g cm-2)	range (g cm-2)
A2	0.75	285.1	255.1	11.8	5.54	2.47	0.169	0.045
A5	2.5	230.0	200.0	11.8	5.30	2.47	0.613	0.118
A9	6.5	220.4	190.4	11.9	5.25	2.48	1.653	0.134
A11	8.5	178.7	148.7	11.8	5.00	2.47	2.194	0.134
A13	11	168.6	138.6	11.4	4.93	2.44	3.082	0.305
A15	15	154.6	124.6	12.1	4.83	2.49	4.318	0.306
A19	23	110.0	80.0	10.8	4.38	2.38	6.939	0.332
A25	35	31.5	1.5	10.1	0.43	2.31	11.010	0.341

Regression Output:

Constant		5.46
Std Err of Y Est		0.08
R Squared		0.96
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-0.158	
Std Err of Coef.	0.015	
sedimentation rate	0.197	g/cm2/year

B8.1.2. Core B (Aird's Bay, 13.11.91) 210-Pb results and accumulation rate calculation

	Depth (cm)	210-Pb (Bq/kg)	excess 210-Pb (Bq/kg)	(+/-)	ln excess 210-Pb	(+/-)	Depth (g cm-2)	range (g cm-2)
B1	0.25	311.7	284.7	12.5	5.65	2.52	0.116	0.058
B5	2.5	323.8	296.8	12.6	5.69	2.53	0.872	0.162
B7	4.5	256.7	229.7	14.0	5.44	2.64	1.564	0.175
B9	6.5	297.3	270.3	13.5	5.60	2.60	2.309	0.188
B11	8.5	240.0	213.0	12.4	5.36	2.51	3.028	0.175
B13	11	220.9	193.9	12.4	5.27	2.52	4.109	0.363
B17	19	177.1	150.1	13.5	5.01	2.60	7.231	0.388
B21	27	69.2	42.2	11.2	3.74	2.42	10.021	0.346
B27	39	27.2	0.2	10.2	-1.73	2.32	14.260	0.368
B33	51	27.4	0.4	10.2	-0.98	2.32	18.825	0.377

(using all points)

Regression Output:

Constant		5.86
Std Err of Y Est		0.26
R Squared		0.86
No. of Observations		8
Degrees of Freedom		6
X Coefficient(s)	-0.174	
Std Err of Coef.	0.029	
sedimentation rate	0.178	g/cm2/year

(assuming top point is in mixing zone)

Regression Output:

Constant		5.93
Std Err of Y Est		0.27
R Squared		0.87
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-0.186	
Std Err of Coef.	0.033	
sedimentation rate	0.167	g/cm2/year

B8.1.3. Core C (Deep Station, 13.11.91) 210-Pb results and accumulation rate calculation

	Depth (cm)	210-Pb (Bq/kg)	excess 210-Pb (Bq/kg)	(+/-)	ln excess 210-Pb	(+/-)	Depth (g cm-2)	range (g cm-2)
C1	0.25	288.1	258.1	13.2	5.55	2.58	0.086	0.043
C5	2.5	245.0	215.0	12.1	5.37	2.49	0.648	0.058
C7	4.5	216.3	186.3	11.9	5.23	2.48	1.138	0.061
C9	6.5	313.1	283.1	12.5	5.65	2.53	1.616	0.059
C11	8.5	205.0	175.0	11.6	5.16	2.45	2.091	0.058
C13	11	185.6	155.6	11.4	5.05	2.43	2.859	0.065
C17	19	165.3	135.3	11.3	4.91	2.42	5.012	0.066
C23	31	104.0	74.0	10.8	4.30	2.38	8.370	0.072
C29	43	59.4	29.4	10.2	3.38	2.32	11.836	0.072

Regression Output:

Constant		5.54
Std Err of Y Est		0.17
R Squared		0.87
No. of Observations		8
Degrees of Freedom		6
X Coefficient(s)	-0.144	
Std Err of Coef.	0.023	
Sedimentation rate	0.216	g/cm-2/year

B8.2. Transect 210-Pb Results

Core No. / Depth Interval	210 Pb (Bq/g)	Core No. / Depth Interval	210 Pb (Bq/g)	Core No. / Depth Interval	210 Pb (Bq/g)	Core No. / Depth Interval	210 Pb (Bq/g)
1/0-1	0.1909	4/0-1	0.2661	6/0-1	0.3776	9/0-1	0.3071
1/1-2	ND	4/1-2	ND	6/1-2	ND	9/1-2	ND
1/2-3	0.2261	4/2-3	0.2555	6/2-3	0.4100	9/2-3	0.3391
1/3-4	ND	4/3-4	ND	6/3-4	ND	9/3-4	ND
1/4-5	0.2327	4/4-5	0.2215	6/4-5	0.3651	9/4-5	0.3496
1/5-6	ND	4/5-6	ND	6/5-6	ND	9/5-6	ND
1/6-7	0.1773	4/6-7	0.2125	6/6-7	0.3395	9/6-7	0.3200
		4/7-8	ND	6/7-8	ND	9/7-8	ND
		4/8-9	0.1263	6/8-9	0.2671	9/8-9	0.2466
2/0-1	0.2365			6/9-10	ND		
2/1-2	ND			6/10-11	0.2006		
2/2-3	0.2080	5/0-1	0.2737	6/11-12	ND	10/0-1	0.2907
2/3-4	ND	5/1-2	ND	6/12-13	0.1775	10/1-2	ND
2/4-5	0.1831	5/2-3	0.2583	6/13-14	ND	10/2-3	0.2935
2/5-6	ND	5/3-4	ND			10/3-4	ND
2/6-7	0.1825	5/4-5	0.2131			10/4-5	0.3006
2/7-8	ND	5/5-6	ND	D/0-1	0.2798	10/5-6	ND
		5/6-7	0.1631	D/1-2	ND	10/6-7	0.2540
		5/7-8	ND	D/2-3	ND	10/7-8	ND
3/1-2	0.1672	5/8-9	0.1404	D/3-4	0.2655		
3/2-3	0.1367	5/9-10	ND	D/4-5	ND		
3/3-4	ND			D/5-6	ND	11/0-1	0.1196
3/4-5	0.0991			D/6-7	0.1882	11/1-2	ND
3/5-6	ND			D/7-8	ND	11/2-3	0.0747
3/6-7	0.0877			D/8-9	ND	11/3-4	ND
				D/9-10	0.1686	11/4-5	0.0512
				D/10-11	ND	11/5-6	ND
				D/11-12	ND	11/6-7	0.0463
				D/12-13	0.1400	11/7-8	ND

ND Not determined

B8.3. Sediment Trap 210-Pb Results

Code/ Depth	210-Pb Activity (Bq/g)	(+/-)	Code/ Depth	210-Pb Activity (Bq/g)	(+/-)	Code/ Depth	210-Pb Activity (Bq/g)	(+/-)
ST1-30m	0.4164	0.0184	ST1-85m	0.4580	0.0194	ST1-145m	0.3966	0.0202
ST2-5m	0.0256	0.0017	ST2-60m	0.2391	0.0071	ST2-135m	0.2950	0.0084
ST3-5m	NS	NS	ST3-60m	0.2236	0.0065	ST3-135m	0.3736	0.0097
ST4-5m	0.0823	0.0041	ST4-60m	0.1497	0.0065	ST4-135m	0.3291	0.0114
ST5-5m	NS	NS	ST5-60m	0.2809	0.0093	ST5-135m	0.2769	0.0077
ST6-5m	NS	NS	ST6-60m	0.3301	0.0087	ST6-135m	0.3249	0.0090
ST7-20m	0.0602	0.0030	ST7-60m	0.3507	0.0178	ST7-135m	0.3359	0.0100
ST8-20m	0.1044	0.0042	ST8-60m	0.2265	0.0065	ST8-135m	NS	NS
			ST9-60m	0.3190	0.0098	ST9-135m	0.3024	0.0086
			ST10-60m	0.5412	0.0158	ST10-135m	0.4464	0.0119
			ST11-60m	0.1394	0.0057	ST11-135m	0.2964	0.0094
			ST12-60m	0.2177	0.0075	ST12-135m	0.2818	0.0089

NS No sample